EVENT-RELATED POTENTIAL STUDIES OF EXPLICIT RETRIEVAL FROM MEMORY

Kevin Allan

A Thesis Submitted for the Degree of PhD
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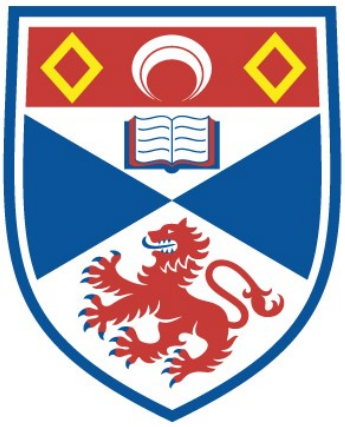
University of St Andrews



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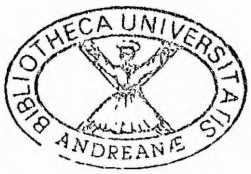

A thesis submitted to the University of St Andrews for the degree of Doctor of Philosophy in the School of Psychology

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Most extra-special thanks and love to Hilary.

Abstract

In six studies, Event-Related Potentials (ERPs) were employed to investigate the neural basis of conscious (explicit) retrieval from long term memory. The studies provide the first detailed reports of ERP effects associated with explicit retrieval on tests of word-stem (e.g. TRE__) cued recall and stem completion. The relationship between the cued recall ERP effects and those previously observed on other tests of memory was also investigated. This was done by directly contrasting ERP correlates of explicit retrieval on the cued recall and recognition memory tasks. Two features of the cued recall and recognition memory ERP effects were found to be highly similar: ERP effects for each task were comprised of parietally and frontally distributed components which differed, as a function of task, only in two respects. First, the parietal effect for cued recall appeared to be somewhat delayed in onset latency relative to that for recognition memory. Second, the hemispheric asymmetry of the frontal effect for cued recall was less marked than that for recognition memory.

The two ERP components were interpreted in terms of processes contributing to the recollection of previous episodes in which words were presented for study. A basic distinction between retrieval and post-retrieval processes was invoked to provide a functional account for the two components. The parietal component was related to retrieval processing associated with 'old/new' judgements. The frontal component was related to post-retrieval processing of retrieved information, which may be more under strategic control, and therefore sensitive to factors extrinsic to those affecting retrieval success per se. In conjunction with the findings of other ERP studies of long term memory, the present results suggest that similar electrophysiological and cognitive processes may be involved in retrieval and post-retrieval processing on a wide range of memory tasks. It is proposed that, under certain conditions, a common feature of these tasks may be the requirement to engage working memory, to monitor explicit retrieval processing.

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FIGURES

1.0 Memory and Consciousness

1.1 Introduction

The distinction between conscious ('explicit') and unconscious ('implicit') memory retrieval (Graf and Schacter, 1985) is a major focus of contemporary research within cognitive neuroscience (e.g. Richardson-Klavehn and Bjork, 1988; Schacter, 1987; 1992; Schacter, Chiu and Ochsner, 1993; Schacter and Tulving, 1994). Explicit memory refers to retrieval accompanied by the experience of remembering, in particular the knowledge that what one is remembering is details of a specific past episode. Implicit memory refers to retrieval which occurs without such experience. The terms explicit and implicit are preferred to the more conventional 'conscious' or 'unconscious', since the latter terms connote differences in state of awareness and/or retrieval intentionality; that is, whether or not retrieval processes are voluntarily engaged (Gardiner and Java, 1993).

Explicit retrieval is typically measured by 'direct' memory tests, which require subjects to 'recollect' information studied in specific prior episodes (e.g. recognition or recall tasks). The term recollection is used here exclusively to denote explicit memory associated with the retrieval of information from past episodes, following the widely held view that explicit memory is best considered as the conscious retrieval of information presented in specific prior episodes (e.g. Jacoby and Kelley, 1992; Tulving, 1983). By contrast, implicit retrieval is typically revealed by bias in performance on 'indirect' tests, which do not rely upon a subject's ability to use his or her memory to perform a task. For example, in 'word-stem completion', subjects study a list of words (e.g. BRANCH), and are then presented with a list of word-stems (e.g. BRA), some belonging to studied items. Subjects are instructed to complete stems with the first word that comes to mind, but even if unaware of the connection between study and test stimuli, subjects can be biased to complete stems

with studied rather than unstudied items (e.g. BRANCH rather than BRAIN) (Schacter, Bowers and Booker, 1989). Biases such as this are commonly termed 'item specific priming effects' (e.g. Moscovitch, 1994; Roediger and McDermott, 1993), to distinguish them from other implicit expressions of memory, e.g. some forms of classical conditioning, which are also held to be independent of explicit memory (Squire, 1994).

The principal basis for the functional distinction between explicit and implicit memory comes from findings of dissociations between performance on direct and indirect tests, with both normal and memory-impaired subjects (e.g. Richardson-Klavehn and Bjork, 1988; Schacter, 1994; Schacter, Chiu and Ochsner, 1993; Rugg, 1995). One important trend in current research is the attempt to fully relate the neural basis of memory processes engaged by different kinds of direct and indirect task. Effort to do so is complicated by the knowledge that there probably is not a one-to-one mapping between systems or processes postulated by theories of memory and the underlying neural structures which may instantiate the theoretical constructs (e.g. Buckner and Tulving, 1995). To further complicate matters, there is a growing realisation that a given task may not be a 'pure' measure of a single kind of memory process, which means that experimental methodology must be adapted to appropriately take account of this concern (Dunn and Kirsner, 1989; Jacoby, 1991; Jacoby and Kelley, 1992).

Patterns of neural activity recorded at the scalp (event-related potentials, or ERPs) can be used to identify neural activity associated with memory processes engaged by different direct and indirect tasks (e.g. Rugg, 1994). This thesis presents the results of six studies employing this technique. The first experiment to be presented (chapter 5) is an exploratory study of ERPs and explicit memory on the direct test of word-stem cued recall. This initial study was carried out for two reasons. First, there are no published ERP studies of cued recall (aside from a brief report by Haist and Kutas, 1994; and also studies of encoding processes and their relation to subsequent cued recall, e.g. Paller, Kutas and Mayes, 1987). But secondly, a number of ERP studies

of the direct 'recognition memory' task have shown that recollection is associated with a particular ERP signature (e.g. Smith, 1993; Wilding, Doyle and Rugg, 1995). This ERP effect, discussed fully in Chapter 3, is a robust and highly reliable phenomenon observed on a variety of different recognition tasks. Whether this effect is a general index of recollection, or is specific to certain tasks, is not known. One of the aims of the first study presented in this thesis was therefore to find out if ERPs are sensitive to recollection on another kind of direct task.

ERPs can also provide a covert means of monitoring subjects awareness on indirect tasks. As discussed in more detail below, recent concerns have been raised over how 'pure' indirect tasks are as measures of implicit memory, or priming (e.g. Bowers and Schacter, 1990; Richardson-Klavehn and Gardiner, 1995). A particular concern is over the 'contamination' of indirect tasks by the deliberate use of intentional retrieval strategies, contrary to the task instructions. These concerns are directly addressed by experiments 2 and 3 of this thesis, in which ERP studies of stem completion are presented. The purpose of these studies is to show whether explicit memory, resulting from a voluntary or an involuntary retrieval strategy, is a feature of task performance, employing ERPs to monitor on-line the neural activity associated with memory retrieval. These studies also aim to show whether or not ERPs are sensitive to implicit retrieval on this task. The subsequent experiments 4, 5 and 6 all provide further investigations of the relationship between ERP effects observed on the cued recall task and those previously observed on the recognition memory task. These studies are introduced more fully in their respective chapters (8, 9 and 10).

In order to provide a context for the ERP studies presented in this thesis, the remainder of this chapter provides a succinct review of research on explicit and implicit memory. The review is organised into three major sections, focused around influential 'systems' and 'processing' frameworks (e.g. Roediger, 1990; Squire, 1992; 1994; Tulving and Schacter, 1990) which guide a great deal of research in the field. The first section provides a concise overview of theories on the functional and

neuroanatomical organisation of processes supporting implicit and explicit retrieval. In the second section, studies of stem completion and cued recall are introduced in more detail, so as to describe and contrast the specific memory processes thought to be engaged by these tasks. This section ends on the notion of task and process 'purity' (Jacoby, 1991), with reference to the cued recall and stem completion tasks, to illustrate problems in interpreting experimental effects in light of the impurity of measures of memory. The third and final section reviews studies of cued recall and stem completion which have employed methods to eliminate or reduce the impurity of each task as a measure of explicit and implicit memory, respectively.

1.1 Systems Models of Memory

The pattern of performance of amnesic patients on direct and indirect tasks has been particularly influential in the development of 'systems' theories of memory. These theories attempt to model memory function in terms of neurologically and functionally distinct memory systems (e.g. Cohen and Squire, 1980; Tulving and Schacter, 1990; Squire, 1992; Tulving, 1983). For example, amnesic patients are severely impaired on direct tasks, but exhibit relatively spared performance on most indirect tasks (for reviews see Moscovitch, Vriezen, and Goshen-Gottstein, 1993; Shimamura, 1986; 1993). Thus, to the extent that direct tasks provide a measure of explicit retrieval, and indirect tasks implicit retrieval, one can infer that amnesics suffer from a devastating impairment of explicit memory, coexisting with relatively spared implicit memory. However, this characterisation of amnesia is merely a redescription of the amnesic deficit. That is, the account does not detail the functional characteristics of the damaged (and spared) neural circuits associated with amnesia, and more particularly does not have anything to say about why damage to such circuits should apparently involve a disorder of memorial awareness (Schacter, 1992).

An important component of systems models therefore deals with the functional interactions between medial temporal lobe brain structures (damage to which is associated with anterograde amnesia) and other subcortical and cortical systems. Critical areas which comprise the medial temporal lobe memory system include the hippocampal formation and adjacent medial temporal neocortex, the midline thalamus and the cholinergic nuclei of the basal forebrain (Mayes, 1988; Squire, 1987; Squire and Zola-Morgan, 1988; 1991; Zola-Morgan and Squire, 1993). Together, these regions make up a 'core' memory system which is necessary, but not sufficient, for explicit retrieval. The function of the core memory system is not entirely understood, and accordingly a number of models attempting to describe its operations have been proposed (e.g. Damasio, 1989a,b; Mclelland, McNaughton and O'Reilly, 1995; Marr, 1971; O'Keefe and Nadel, 1978; Teyler and Discenna, 1986). In the following paragraphs, two systems models are described, those due to Cohen, Squire and colleagues (e.g. Cohen and Squire, 1980; Squire, 1992; 1994) and Tulving, Schacter and colleagues (e.g Tulving and Schacter, 1990). Both models have had a considerable impact upon behavioural research with human subjects.

1.1.1 Declarative and Non-Declarative Memory

The systems model of Cohen, Squire and colleagues (Cohen and Squire, 1980; Squire and Knowlton, 1994; Squire, Knowlton and Musen, 1993; Squire, 1992; 1994) postulates that the core medial temporal lobe memory system is critical to the formation of 'declarative' memories. The model also postulates a distinct set of cortical and subcortical memory systems collectively referred to as non-declarative (or 'procedural') memory. Critically, explicit retrieval is mediated by declarative memory. Retrieval from non-declarative memory is not associated with awareness. This conclusion is based primarily on findings with amnesic subjects, where performance on indirect tasks has been shown to be intact (i.e. not different from control subjects). Declarative memories have the important properties of 'representational promiscuity' and 'flexible access' which distinguish them from non-declarative memories. These properties are a consequence of the 'relational'

processing which is carried out by the core memory system. These important notions are discussed below.

Briefly, the core memory system processes different kinds of relation between elements of experience (e.g. the relative size, colour, position, shape, temporal contiguity, etc, of different objects comprising events). The core memory system participates as the 'hub' of a network linking such elements, with the result that subsequent activation of any given element (e.g. by the presentation of a retrieval cue) can give rise to the activation of other parts of the network to which the element has been related. The crucial consequence of this is that information can potentially be accessed (retrieved) in all manner of situations, novel contexts etc, by various forms of retrieval cue, making the information available to guide behaviour in situations quite distinct from those in which it was acquired.

In contrast, non-declarative memory results from the 'tuning' of processing which is carried out by 'modules' operating independently of the core system. The idea is that these modules provide the input to the core memory system, but the processing carried out by the modules is itself gradually, incrementally, changed as items are processed. Such changes are the basis of implicit expressions of memory. Because this 'tuning' of processing is specific to particular modules, the expression of non-declarative memory in task performance, such as a bias towards completing stems with studied items, is highly inflexible and occurs chiefly on tasks which engage processing which overlaps with that carried out during aquisition or study periods. On tasks which do not require the processing capabilities of the given module(s) activated during aquisition, little or no evidence for item specific priming will be obtained.

1.1.2 Episodic and Semantic Memory

In another systems framework provided by Tulving, Schacter and colleages (Tulving, 1972; 1994; Tulving and Schacter, 1990), a distinction is made between

two components of the declarative memory system; episodic (autobiographical) memory and semantic memory (see Dosher (1984), McKoon, Ratcliff and Dell (1986) and Tulving (1986) for discussion of some problems with this distinction). Tulving's framework postulates two different kinds of explicit retrieval, supported by the episodic and the semantic systems, respectively (Tulving, 1983; 1985; 1993-broadbent). Episodic retrieval is associated with explicit memory for details of specific past episodes (i.e. recollection; however, Tulving also terms this 'autonoetic' awareness, to denote that such memories always have a self-referential quality). Semantic memory is associated with explicit knowledge of facts, e.g. the names of past managers of Raith Rovers Football Club, which come to be represented separately from the particular events in which such facts were acquired (Tulving terms this noetic awareness). In this model, the functional role of the core memory system is not elaborated in any further detail beyond that given above.

1.1.3 A Processing Mechanism for Explicit and Implicit Retrieval?

A critical aspect underlying the systems models is that the memory traces which are retrieved, or re-activated, during test are not actually stored within the core memory system (e.g. Damasio, 1989a,b; Johnson and Chalfonte, 1994; Nyberg et al., 1995). Rather, the function of the core memory system may be to coactivate traces of past processing which reside within the neural systems to which it is reciprocally connected (Cohen and Eichenbaum, 1993). According to this proposal (and see also Damasio and Damasio, 1994; Teyler and Discenna, 1986), the core system effectively stores the 'addresses' of the multiple regions in which information was processed during specific episodes. It is the reactivation of these 'input' areas during retrieval which must therefore provide the neural basis for explicit memory (e.g. Shacter et al., 1996)[1]. Retrieval is thus seen as a 'playing back' of activity in regions involved in initial processing of information during learning. Brain regions important for initial encoding may therefore also be active during retrieval. While

[1] It is not clear, at least to me, why explicit memory should depend on the cortical reactivation of previous processing by the core memory system. If correct, this may be a consequence of the inability of the cortical systems alone to 'talk to one another' in such a manner as to give rise to coactivation across multiple, possibly functionally distinct regions.

entirely identical processes may not be involved during aquisition and retrieval (Craik et al., 1996), it is nonetheless widely accepted that there is probably some overlap in the regions activated during encoding and retrieval of similar kinds of information.

These general ideas bear similarity to the psychological frameworks of 'transfer appropriate processing' (TAP, Morris, Bransford and Franks, 1977), and encoding specificity (Tulving and Thomson, 1973), which have guided a great deal of research on memory over the last few decades (Baddeley, 1991; Craik et al., 1996). The importance of the TAP model to the understanding of memory has been emphasised by recent attempts to incorporate TAP within systems models, as a 'principle' which relates to both declarative and non-declarative memory (Keane et al., 1991; Roediger, 1990; Tulving and Schacter, 1990).

1.1.3.1 Transfer Appropriate Processing (TAP)

TAP provides a useful framework to conceptualise how different cortical regions, specialised for the processing and representation of different stimulus attributes, might support both explicit and implicit memory (Cohen and Eichenbaum, 1993; Tulving and Schacter, 1990). TAP refers to the relationship between the processing operations engaged when memories are encoded at study, and those engaged when memory is subsequently tested. Briefly, the TAP framework predicts that performance on a memory test will benefit to the extent that operations at study overlap with those performed at retrieval. Thus, 'data driven' tests, which rely predominantly upon presemantic, perceptual representations of items may be distinguished from 'conceptually driven' tests which, in addition, require comprehension of items and their relationship to stored knowledge (note that this is not the only processing distinction which has been made, e.g. see Craik et al., 1996).

Using this framework, direct and indirect tests can be classified according to their processing requirements. For example, in the direct 'graphemic cued recall' task,

subjects are asked to recall studied items (e.g. CHILD) using graphemically related cue items (e.g. CHILL). Performance on such data-driven tasks can be functionally dissociated from performance on conceptually driven direct tasks such as 'semantic cued recall', where recall of studied items is cued by semantically related items (e.g. BABY). Thus, graphemic cued recall is sensitive to manipulations of the sensory modality in which items are presented at study and test, but not to whether the meaning of items was processed at study (Blaxton, 1989). Performance on the semantic cued recall task shows the reverse pattern. Similar patterns of functional dissociation can also be demonstrated for indirect tasks (Roediger and McDermott, 1993).

Thus irrespective of whether a task is direct or indirect, the TAP approach appears to account for the observed patterns of dissociation which result from the selective effects of independent variables on task performance. Such findings with normal subjects have required that systems models take better account of how memory systems may process information. In recent work, Cohen and Eichenbaum (1993) briefly note that retrieval from declarative memory may be subject to constraints broadly captured by the TAP framework, but suggest that these constraints affect the success of retrieval, and do not play a role in determining the possible use of declarative memories once retrieved. If correct, this proposal could account for findings with normal subjects, where performance on two direct tasks can be dissociated as a function of the nature of the processing requirements of each task (as is the case for graphemic and semantic cued recall, see example above). In such cases, the provision of specific retrieval cues may act to constrain the success of explicit retrieval attempts. Importantly, it seems plausible that the critical function of retrieval cues is the manner in which they influence processing at test. Thus, retrieval cues may be used to alter the overlap between study and test processing. And if retrieval cues sufficiently constrain the type of processing carried out at test, then resulting memory performance may indeed come to reflect dissociations of the form predicted by TAP.

1.1.3.2 'TAP' and Memory Impairment

However, work with memory-impaired subjects has revealed neurological dissociations which do not entirely complement the functional ones described above. Patients with Alzheimer's-type dementia have been observed to show normal data-driven, but impaired conceptually-driven priming (Gabrielli et al., 1994; Keane et al., 1991). The pattern of normal and impaired priming effects in Alzheimer's disease is thought to reflect the damage caused by the disease to regions of temporal and inferior parietal cortex responsible for representing lexical and semantic information, leaving intact more posterior cortical regions which subserve pre-semantic perceptual processing. While this interpretation has received some recent criticism (Randolph, Tierney and Chase, 1995), the integrity of different specialised cortical areas appears to be necessary and perhaps sufficient for expressions of implicit memory for those stimulus attributes that are selectively processed and represented by these regions.

In addition, Blaxton (1992) compared the performance of mildly amnesic, temporal lobe epilepsy patients on conceptual- and data-driven direct and indirect tasks. Blaxton found that the patients' performance was relatively intact on the data driven tasks but was impaired on the conceptually driven tasks. She suggested that these findings were consistent with the TAP account, in so far as they indicated that amnesic subjects were impaired in their ability to perform a certain type of processing, rather than their ability to explicitly retrieve items per se. However, the findings from three other studies have failed to confirm the results of Blaxton's study (Carlesimo, 1994; Cermak, Verfaellie and Chase, 1995, Gabrielli et al., 1994). In these studies, amnesic patients have shown normal levels of priming on both data- and conceptually-driven indirect tests, while performance on direct tasks was impaired, irrespective of the nature of the processing demanded by the task. In the study carried out by Cermak, Verfaellie and Chase, which closely replicated the design of Blaxton's study, the authors suggested that Blaxton's findings may have been a consequence of the mild amnesia and pathology characteristic of her patient

group, implying that these patients may not have been able to process information conceptually because of damage to their temporal lobes. In fact, Blaxton's patients may have exhibited damage to cortical regions compromised in Alzheimer's patients who have also been shown to exhibit a selective impairment of conceptual priming, as noted above.

As a principle of memory, TAP therefore does not account for the *inability* of amnesic subjects to perform direct tasks regardless of the type of processing which they require, or their *ability* to perform certain indirect tasks regardless of their particular processing demands. It is clear that there are aspects of the operation of memory which are not captured by TAP. One of these is obviously whether the task instructions make demands upon the core memory system, damaged in amnesic patients, which enables the explicit retrieval of episodic information. However, it is clear from the study of amnesia that implicit retrieval can occur independently of the processing carried out by the core medial temporal lobe memory system. In consequence, implicit retrieval may in large part depend upon brain regions distinct from those damaged in amnesic patients.

1.1.3.3 Summary

The systems models and the processing approach of TAP are thus seen to be complementary (Roediger, 1990). TAP may be used as a framework within which to explore the nature and interaction of processes engaged at study and test, while systems models in addition provide an account of the organisation of these processes in terms of their neural substrate and their relationship to explicit and implicit memory. Importantly, some combination of processing and systems models would seem to be necessary to account for the data from studies of memory impairment.

1.1.4 Working-With-Memory

Successful declarative retrieval accompanied by explicit memory is not a sufficient basis for performance on all kinds of direct task. The additional contribution of distinct 'systems' appears to be necessary for the ability to make further, more 'fine-grained' distinctions about the attributes of previously experienced episodes. For example, the ability to judge when and where a particular word was last seen, or to judge whether a studied word was presented visually or auditorially. Such discriminations will hereafter be called 'source memory'. Perhaps the best developed functional account of source memory has been provided by Johnson and colleagues (Johnson, 1992; Johnson, Hashtroudi and Lindsay, 1993; Johnson, and Chalfonte, 1994). According to this approach, source tasks are treated as a form of cued recall task. That is, when presented with an item at test (e.g. the word 'CLOCK') the subject has to think back to a previous episode in which 'CLOCK' was presented, and then report on details of the episode, such as the nature of the study task with which 'CLOCK' was encoded. The test item is thus a retrieval cue which aids the search for a specific attribute of a specific episode. Other forms of source task may require subjects to provide a source for a given test item. That is, to state where and when the item was last presented. These different kinds of source task may depend upon different mechanisms, according to the nature of processes engaged at encoding and the subsequent processes engaged at retrieval, but in common is the requirement to discriminate aspects of a particular prior episode. The term recollection may thus be something of a general label, covering a number of possibly distinct cognitive / neural processes (Johnson and Chalfonte, 1994), each of which supporting the explicit retrieval of different kinds of information.

Source memory appears to depend not only on the contribution of the core medial temporal lobe memory system, but also on the contribution of processes instantiated within the frontal lobes. The contribution of the frontal lobes to such judgments has been specifically suggested by Moscovitch and colleagues (Moscovitch and Umilta, 1991; Moscovitch, 1992; 1994), and also by Squire and Knowlton (1994), as an additional component of declarative memory. Moscovitch contends that information sufficient to judge a test item (e.g. 'CLOCK') as having been studied is 'delivered'

by the medial temporal lobe system (Moscovitch, 1992), which he appears to view as a dedicated 'module' which provides only associative information. That is, the system mediates the explicit retrieval of information associated at study with the retrieval cues presented at test (Moscovitch, 1994). This information is sufficient to generate a sensation of 'pastness', which forms one basis for accurate memory judgments on tasks such as recognition memory, which require only that old and new items be discriminated.

In contrast, memory for 'contextual detail' from study episodes requires that associatively retrieved information be further integrated with study context (see also Squire, 1994; Squire and Knowlton, 1994). This additional processing may depend on the integrity of the frontal lobes (Squire, 1994). Studies of frontal lobe patients have lead to the proposal of a specific 'source amnesia' deficit resulting from frontal lobe damage (e.g. Janowsky, Shimamura and Squire, 1989; Schacter, Harbluk and McLachlan, 1984; Shimamura and Squire, 1987). For example, Glisky, Polster and Rothieaux (1995) showed recently that memory for items (recognition memory) and memory for source are neurologically dissociable. Elderly subjects in this study were assigned to one of two groups, based on their scores on test batteries designed to assess either medial temporal or frontal lobe function. Performance on the tests of frontal function was positively correlated with performance on a test of source memory, but was uncorrelated with performance on a test of recognition memory for the same items. In contrast, performance on the tests of medial temporal lobe function was positively correlated with performance on the recognition test and uncorrelated with performance on the source task. Glisky, Polster and Rothieaux argued that this double dissociation suggests different neural substrates for performance on the item and source memory tasks (but see Richardson-Klavehn, Lee, Joubert and Bjork, 1994, for a critique of medial temporal lobe theories of memory; Parkin, Leng and Hunkin, 1990; Parkin and Fairbairn, 1989).

Moscovitch (1994) points out that the function of the frontal lobes cannot simply be to provide a contextual basis for retrieved item information (e.g. see Stuss, Eskes and Foster, 1994). He does note however that the frontal 'systems' may provide the basis

for the intelligent, goal and strategy guided *use* of the medial temporal lobe system. To denote this function, the frontal systems are termed 'central structures', whose function is 'working-with-memory' (Moscovitch, 1992). Similar suggestions have been put forward by N.J. Cohen (cited in McLelland, McNaughton and O'Reilly, 1995), and Petrides, Alivisatos and Evans (1995). Baddeley (1996) has also begun to consider the role of the working memory 'central executive' (Baddeley, 1986; Baddeley and Hitch, 1974) in the retrieval, maintainance and manipulation of information re-activated from store in long term memory. This exciting confluence of ideas from a number of different approaches reflects the growing realisation that long term memory, particularily declarative memory (and hence explicit retrieval) is actively engaged in the service of cognition, and is not merely a passive store [2].

1.1.5 Systems Models of Memory: Summary

The above review has covered a large number of theoretical and empirical studies of long term memory. Current ideas on the functional and neuroanatomical basis of explicit and implicit retrieval were presented. The memory processing mediating explicit and implicit retrieval was distinguished by virtue of the involvement of a core medial temporal lobe memory system, critical for explicit expressions of memory. Item specific implicit retrieval is thought to rely upon processing carried out by regions of cortex, as yet unspecified in any detail, which alone are sufficient only for such expressions of memory. The contribution of frontal lobe based systems to explicit memory was also discussed. This contribution was presented in terms of the source memory approach, advocated primarily by Johnson and colleagues.

In the following section, the cued recall and stem completion tasks are introduced. These tasks have been widely used to contrast the functional neuroanatomy of

[2] I believe there are parallels here with the debate in the early 1970s over how best to characterise short term memory. The resolution of this debate seemed to be provided by the notion of a short term working memory system of multiple components (Baddeley and Hitch, 1974). It may be that a similar kind of development will be evident in the understanding of long term memory, so that it becomes conceptualised as an 'active' system, which will place as much emphasis on how stored information is used in the service of cognition, as well as where and how it is stored and retrieved.

explicit and implicit retrieval. Its fair to say that there is little interest in these tasks per se. Rather, the tasks are employed to give insight into explicit and implicit retrieval. In recent years, each task has been widely studied because of the 'impurity' of each as a measure of specific forms of retrieval.

1.2 Word Stem Cued Recall and Stem Completion

To recap, cued recall requires subjects to retrieve studied items (e.g. BRANCH) with the aid of some form of retrieval cue. Word stem cued recall tasks provide stems of words to aid recall (most typically the first three letters of words, e.g BRA__, though see Tulving and Watkins, 1973). In contrast, on stem completion tasks, following a study phase, subjects are asked to complete stems with the first word to come to mind (Warrington and Weiskrantz, 1968; 1970; 1974). Cued recall is a direct task. Stem completion is an indirect task. Memory is measured, on each task, by the proportion of stems correctly completed with studied items beyond that predicted on the basis of chance (which for stem completion is typically estimated by the proportion of 'correct completions' made with unstudied experimental items). In the following sections, a review of work with stem completion and cued recall is presented, in order to distinguish the two tasks functionally. This review also serves to highlight problems in interpreting the findings of studies employing this task comparison approach.

1.2.1 Functional Dissociations

There are now a number of studies which have directly contrasted performance on cued recall and stem completion (e.g. Craik, Moscovitch and McDowd, 1994; Richardson-Klavehn, Gardiner and Java, 1994). A number of studies have also contrasted one or the other task with different kinds of direct and indirect task (Richardson-Klavehn and Bjork, 1988). Generally, the aim of all such studies has been to contrast performance on an indirect and a direct task as a function of some independent variable(s). The observation of dissociations in the effects of these

variables on direct and indirect tasks then forms the basis for functional distinctions between each class of task, or within each class but between tasks which themselves differ in, for example, their processing requirements (see Blaxton (1989) for a classic example of this approach).

It is uncontroversial to state that word-stem cued recall is mediated by recollection. That is, by the ability to bring to mind details of prior episodes in which the study item belonging to the retrieval cue may have been presented. This is not to say that the processes mediating cued recall are by any means understood. Recollection, as noted in the section above, is probably a rather too general label for a number of different processes which have in common the feature of explicit retrieval. However, *it is* controversial to state that cued recall is a 'pure' measure of recollection, in the sense that only recollection contributes to accurate cued recall performance (Jacoby, Toth and Yonelinas, 1993; and see the section 1.3 of this chapter below).

Obviously, recollection could also lead to a subject giving a correct completion on the stem completion task. However, based on the results of studies with amnesic patients (e.g. Graf, Squire and Mandler, 1984; Squire, Shimamura and Graf, 1987; Warrington and Weiskrantz, 1974), it is clear that item specific priming on stem completion can be intact even though performance on cued recall, and other direct tasks, is drastically impaired. Since such patients appear to be unable to recollect information, it follows that there are processes independent of recollection which mediate performance on stem completion tasks. However, this is not to say that stem completion is a pure measure of implicit memory, in the sense that subjects never recollect the prior occurrence of correct completions at study (Jacoby, Toth and Yonelinas, 1993; again, see the final section below for further elaboration on this point).

1.2.1.1 Depth of Processing

The effects of depth of processing manipulations (Craik and Lockhart, 1972; Craik and Tulving, 1975) on cued recall and stem completion have been widely studied

(Brown and Mitchell, 1994). A large variety of different study tasks have been employed to manipulate study depth of processing (Brown and Mitchell, 1994). The most commonly employed variant of the manipulation is to alter the degree to which the meaning of items is processed at study. For example, half of all study items may be studied with a task which requires the number of consonants in the word to be counted. The remainder may be studied with a task which requires the meaning of the word to be rated in terms of its 'pleasantness', or how well it is liked by the subject.

Initial studies contrasting word stem cued recall and stem completion as a function of depth of processing appeared to show selective effects of the manipulation on the word stem cued recall task (e.g. Graf and Mandler, 1984). Such findings led to the widely held view that performance on stem completion was insensitive to depth of processing, while on word stem cued recall a large effect of depth of processing could be observed. The interpretation given to such effects was that the depth of processing manipulation affected the success of intentional retrieval strategies on cued recall (Richardson-Klavehn, Gardiner and Java, 1996). Because stem completion does not encourage such strategies, performance on this task was held to be largely unaffected by depth of processing. This is a standard interpretation given to depth of processing effects (Richardson-Klavehn, Gardiner and Java, 1996).

The conclusion that indirect tasks, and stem completion in particular, are unaffected by study depth of processing is actually not borne out by systematic review of the literature. Brown and Mitchell (1994; see also Challis and Brodbeck, 1992) in particular carried out a very useful meta-analysis of the effects of depth of processing on performance on indirect and direct tasks, sampling widely from the literature over the years 1981 to 1993. The meta-analysis clearly showed that across a wide variety of indirect tasks, including stem completion, depth of processing was associated with weak but often statistically significant effects. The direction of the effect was identical to that found for cued recall, i.e. deeper processing of items at study often enhanced the probability of stem completion. Brown and Mitchell's

analyses do, however, show that depth of processing typically exerts a much weaker effect on stem completion than on word stem cued recall, and on conceptually driven direct tasks in general.

On stem completion, the weak effects of depth of processing may arise because the task involves a form of implicit memory which depends on conceptually driven processing (Challis and Brodbeck, 1992); that is, a form of conceptual priming (Roediger and McDermott, 1993). An alternative interpretation of the weak depth of processing effects on stem completion is that they reflect a 'contamination' of performance by voluntary retrieval and explicit memory (Richardson-Klavehn and Bjork, 1988; Schacter, Bowers and Booker, 1989; Toth and Reingold, 1996). It is not at all clear which interpretation of the depth of processing effects on stem completion is correct. One approach to answering this question has been to investigate the effects of manipulations of perceptual stimulus features on performance on direct and indirect tasks, including word-stem cued recall and stem completion. Examples of this approach are given below.

1.2.1.2 Cross-Modal Priming

'Cross-modal priming' (Toth and Reingold, 1996) on the stem completion task occurs when visually presented stems are completed with auditorially studied items (or vice versa) more often than predicted by chance. The typical finding is that cross-modal priming is reduced, but not eliminated, compared to within-modality priming (Bassili, Smith and McLeod, 1989; Kirsner, Dunn and Standen, 1989; Rajaram and Roediger, 1993). The logic behind this manipulation of perceptual stimulus features is that by radically altering the perceptual format of items from study to test, the transfer of perceptually-based processing from study to test will be reduced or eliminated. As a result, the influence of memory at test must be predominately mediated by a process or system which deals with modality aspecific semantic or episodic memory representations. The most 'extreme' form of this kind of manipulation involves changing the modality of item presentation from study to test.

The reduction of cross-modal priming relative to within-modal priming suggests that stem completion priming is composed of two components. One is a modality independent, conceptually-driven form of priming (Weldon, 1993; and see Kirsner, Dunn and Standen, 1989). So the manipulation of study / test modality provides some support for the notion that stem completion priming includes a conceptual component. This component may be sensitive to manipulations of depth of processing at study, and therefore the depth of processing effects observed for stem completion (Brown and Mitchell, 1994) may, after all, reflect implicit memory. However, once more an alternative possibility is that cross-modal priming may reflect the contamination of task performance by intentional retrieval strategies (Toth and Reingold, 1996).

The other component of priming on the stem completion task may be perceptually based, and therefore sensitive to changes in study / test modality, hence leading to a reduction in levels of cross-modal priming. There is some evidence that stem completion, and cued recall, may depend upon memory processes that are instantiated by regions of right posterior cerebral cortex and right medial temporal lobe structures. These processes may be involved in mediating the modality specific, perceptually based component of priming. Behavioural evidence for a right hemisphere contribution to cued recall and stem completion came initially from studies employing the divided visual field technique. For example, Marsolek et al. (1994) observed that word stem cues gave rise to more accurate cued recall and stem completion when presented to the left than to the right visual field. These findings led Marsolek et al. to propose the existence of a visual form-specific memory system (see also Keane et al, 1991; Moscovitch, 1994; Schacter, Chiu and Ochsner, 1993; Tulving and Schacter, 1990) involving regions of the right medial temporal lobe and cerebral cortex which interact with one another to support the explicit retrieval of visual features of studied items. Marsolek et al. suggested that regions of posterior right cerebral cortex may alone mediate the implicit retrieval of such information to support priming on the stem completion task.

Marsolek et al. (1994) based their neuroanatomical claims on their own divided visual field findings, together with the results of functional imaging studies of cued recall and stem completion which employed positron emission tomography (PET) (Buckner et al., 1995). In these PET studies, evidence for a right hemisphere contribution to cued recall and stem completion was found only when visual format (letter case and study / test modality) was maintained between study and test: performance on both tasks was found to be associated with activation of right hippocampal formation (Buckner et al., 1995), and with decreases in activation in regions of left and right occipital cortex. The hippocampal activations were only observed when visual features were maintained across study and test. These activations were interpreted as reflecting explicit retrieval on both tasks, thus supporting the notion that performance on stem completion may be accompanied by explicit retrieval.

The activations within the left and right posterior cortex were differentially affected by changes in visual stimulus format. For the right hemisphere, the focus of activity changed slightly with manipulations of visual format. Activity within this region was therefore sensitive to the visual format of stimuli across study and test presentations. This led Buckner et al. (1995) and Marsolek et al. (1994) to posit a posterior right hemisphere form-specific memory system contributing to priming (see Keane et al, 1991; Moscovitch, 1994; Schacter, Chiu and Ochsner, 1993; Tulving and Schacter, 1990). In contrast, PET activations within the posterior left hemisphere did not change as a function of the visual format manipulations. Based on this finding, Marsolek et al. (1994) also suggested a posterior left hemisphere locus for another priming system. This system, in contrast to the right hemisphere priming system, may represent visual information in a more 'abstract' form which is less sensitive to changes in visual format (again, see Keane et al, 1991; Moscovitch, 1994; Schacter, Chiu and Ochsner, 1993; Tulving and Schacter, 1990).

The results of the PET studies described above are consistent with data from amnesic subjects which implicate the medial temporal lobes, including the hippocampal formation, in explicit retrieval. These studies also provide some evidence for the activation of medial temporal lobe structures during stem completion, which possibly indicates the occurrence of explicit retrieval on the task. The studies also provide some insight into the functional nature of cortical processes common to stem completion and cued recall under certain task conditions (see also Gabrielli et al, 1994). These processes involve regions of posterior left and right cerebral cortex, and are involved with processing the visual format of study and test items.

1.2.2 Summary

The above section introduced the cued recall and stem completion tasks. Studies which investigated the memory processes contributing to performance on these tasks were reviewed. The review was focused on studies which employed a task comparison methodology, assessing the effects of independent variables on performance on each task. The depth of processing and presentation modality manipulations were introduced as prominent means of distinguishing between the processes supporting cued recall and stem completion. Findings from PET studies were also introduced, to give some insight into the neural processes supporting performance on the tasks. The review emphasised a particular widespread problem with interpreting the effects of experimental manipulations within the task comparison approach. The problem is whether performance measures on the indirect stem completion task are 'contaminated' by explicit memory. Different methods have been advanced to take such considerations into account. These are discussed below in the final review section of this chapter.

1.3 Obtaining a Pure Measure of Explicit and Implicit Memory

Task 'purity' refers to whether a given task (or class of tasks, e.g. direct tasks) provide a pure measure of a single underlying memory process (e.g. explicit memory). The assumption of task purity is an example of a 'transparency assumption' (Dunn and Kirsner, 1989), which is to assume a one-to-one mapping between concepts at different explanatory levels (e.g. equating a particular task with a particular cognitive process). There are other forms of transparency assumption, such as that which equates the operation of a given cognitive process with the activity of a single brain region, or of a given state of awareness (e.g. explicit memory) with the operation of a single kind of memory system (e.g. episodic memory). These are all examples of transparency assumptions which relate concepts at one level of abstraction to those at another by assuming a certain form of mapping across levels.

The problem of task impurity is not trivial. As already indicated above, the possibility of contamination by explicit memory and intentional retrieval tends to render functional interpretations of experimental effects uncertain. In particular, cases where a certain variable, such as depth of processing, has a parallel (similar) effect on a direct and an indirect task become difficult to interpret, since this can occur if subjects treat the nominally indirect task as a direct task, and intentionally retrieve studied items. Contrasts between the performance of normal and memory-impaired subjects may also become problematic. For example, the performance of intact control subjects may exceed that of amnesic subjects on a given indirect task. Because of this, it may be concluded that priming on this task is impaired in the amnesic subjects. This in turn will lead to the conclusion that the brain regions damaged in the patients are responsible for some forms of priming, in addition to explicit retrieval (see Schacter, Church and Bolton (in press), for just such a claim). However, the control subjects may simply have deliberately engaged their intact declarative memory, contrary to the indirect nature of the task instructions. In which case, the observed dissociation is an artefact, and does not provide information on the status of implicit memory in the amnesic subjects. Such confusions are obviously undesirable, and so methods are required which establish either that explicit

contamination does not occur, or at least that such contamination is not reflected in measures of task performance.

It is therefore clear that we must be able to determine if and when subjects performance on indirect tasks is 'contaminated' by explicit retrieval, and if this contamination reflects a shift in retrieval strategy (Mayes, 1992). In a similar vein, it has also been suggested recently that performance on direct tasks may reflect influences which are independent of recollection (e.g. Jacoby and Hollingshead, 1989; Jacoby, Toth and Yonelinas, 1993).

The possibilty of explicit contamination of indirect tests was discussed in detail by Richardson-Klavehn and Bjork (1988), Schacter (1987) and Schacter, Bowers and Booker (1989). These authors considered the problem to have two distinct facets. One concerns the occurrence, or not, of explicit memory during performance on indirect tasks. Another independent factor is whether subjects adopt an intentional retrieval strategy to perform the indirect task, and thus disobey the task instructions. Richardson-Klavehn and colleagues have been particularly active in providing evidence supportive of this distinction between explicit / implicit retrieval, and intentional / incidental retrieval strategies. It is their contention that explicit memory occurs frequently on indirect tasks, irrespective of whether explicit retrieval is intentional or incidental. They hold that parallel effects of manipulations such as depth of processing on direct and indirect tasks (Brown and Mitchell, 1994) do not occur simply because explicit memory occurs on each kind of task. Rather, the parallel effects could reflect the engagement of intentional retrieval strategies on each kind of task. In support of this, Richardson-Klavehn and colleagues have shown that functional dissociations between direct and indirect tests can be observed even when explicit memory is a reliable feature of direct and indirect test performance.

Before discussing the work of Richardson-Klavehn, Schacter and colleagues, an approach taken by Jacoby and colleagues is introduced below which differs somewhat from the standard approach of contrasting performance on direct and

indirect tasks. Jacoby and colleagues have explicitly made the assumption that in practice all tests of memory are impure (Jacoby, 1991). Predicated on this assumption, they have developed a means of pitting the contribution of one process against another, in order to separately estimate the effects of each process on task performance. This process dissociation approach is discussed below. Following this, some criticisms of the PDA, developed by Richardson-Klavehn and colleagues, are presented. The criticisms lead me to reject the PDA as a method of investigating task purity, at least with respect to the stem completion and cued recall tasks. The alternative approaches of Richardson-Klavehn, Schacter and colleagues are then introduced. These have had some influence on the design of the initial ERP studies presented in this thesis.

1.3.1 The Process Dissociation Approach

The process dissociation approach (PDA) was developed by Jacoby and colleagues as a means of analysing the contribution of different processes to performance on memory tasks. The PDA departs from the typical approach adopted by researchers to study explicit and implicit memory, which typically involves a straightforward contrast between performance on direct and indirect tests (but see Hayman and Tulving, 1989 for a different method). The PDA differs from this 'task comparison approach' because it assumes a priori that a given test of memory is not a pure measure of a single memory process or system. Based upon this assumption, procedures are developed to separately estimate the contribution of different bases to performance on the task. The PDA cannot therefore produce evidence to substantiate the claim that a task is impure, since this is the assumption on which the approach is predicated.

However, the PDA is used to demonstrate the effects of experimental manipulations upon one or another postulated basis for task performance. Thus, the procedure assumes multiple bases for performance (i.e. two), whose operation can be studied by employing experimental manipulations of memory. The effects of such

manipulations on each basis can then be contrasted. Various assumptions concerning the relationship between each basis can be explicitly incorporated into the PDA, which represents an additional degree of freedom within the PDA framework. However, as detailed below, this degree of freedom can be construed also as a major drawback.

The typical application of the PDA involves contrasting performance on two tasks (but see Wilding and Rugg (in press), for a single-task version). In an 'inclusion' task, each basis for task performance can give rise to correct responses. For example, an inclusion stem completion task may involve completing each stem with a studied word, or if this cannot be done, simply completing the stem with the first suitable word to come to mind. Under such instructions, there are two possible ways of correctly completing a stem. Either the correct completion could be recollected, or, as a result of the prior exposure at study, the correct completion may 'automatically' come to mind as a completion for the stem. Thus both recollection and automatic influences will act to increase the probability of giving a correct response.

In contrast, 'exclusion' task instructions put each basis for responding in opposition to one another. For example, exclusion stem completion instructions require subjects to complete stems with items which were not studied. Under these instructions, recollection and automatic influences are held to be in 'opposition'; if an item is recollected then it will not be given in response, while automatic influences will lead to studied items coming to mind. It is very important to note here that these automatic influences can *never* be accompanied by explicit memory, because if they were then the subject would exclude the item, as required. This assumption is discussed in more detail below. In any case, if a studied item is given on the exclusion task then it cannot have been recollected. Performance on the two tasks is modeled by the following equations.

$$\text{Inclusion} = p(R) + (p(A) * (1 - p(R))) \quad [1]$$

$$\text{Exclusion} = p(A) * (1-p(R)) \quad [2]$$

p(R) = probability of correct completion on basis of recollection
p(A) = probability of correct response on basis of automatic influence

By substituting for (p(A) * (1 - p(R)) in equation [1],
p(R) = inclusion - exclusion [3]

These equations define the probability of completing a stem with a studied item on each task, under an 'independence' assumption. In plain English, equation [1] states that completion with a studied item may occur if the completion is recollected, or if it comes to mind automatically, taking into account that such influences may on occasion co-occur. Equation [2] states that completion with a studied item will only occur for studied items coming automatically to mind which are not recollected. Simple algebra then affords estimates of p(R) from equation [3], p(A) by substituting for p(R) back into equations [1] and [2]. To derive these estimates, equations [1] and [2] have to be treated as simultaneous. This means that each equation represents the relationship between two 'entities' (i.e. recollection and automatic influences) which are in essence identical on the inclusion and the exclusion tasks. In psychological terms, this means that under the different conditions of the exclusion and inclusion tasks, recollection and automatic influences do not vary, at all. This assumption has itself been widely criticised (e.g. Graf and Komatsu, 1994; Roediger, 1994).

1.3.1.1 An Example

Jacoby, Toth and Yonelinas (experiments 1a and 1b, 1993) employed the PDA to investigate the processes supporting word stem cued recall and stem completion. In these experiments, subjects studied words presented in two separate lists. In the first list items were presented auditorially. In the second list items were presented visually. For this second list, half the subjects saw the items in a full attention condition, and the remainder studied the items with divided attention (employing a concurrent task requiring the detection of target number sequences in a stream of auditorially presented numbers). The purpose of the divided attention manipulation

was to selectively affect the probability of recollection, and to leave unchanged the influence of automatic influences of memory (which by definition should not be dependent upon attention at study). At test, each subject performed interleaved inclusion and exclusion tests, with instructions as given above.

Estimates of the effects of the divided attention manipulation on the probability of recollection and automatic influences were derived in each experiment. As hypothesised, the manipulation had little effect on the estimate of automatic influences represented by p(A). However, the estimate of recollection p(R) was significantly reduced by dividing attention. In conclusion, these findings were interpreted as showing that the two bases for responding (recollection and automatic fluency-based response) were indeed independent of one another. That is, automatic influences represented by the probability p(A) remained invariant over changes in the influence of the intentional use of memory, represented by p(R), the probability of recollection.

1.3.1.2 Criticism of the PDA

The PDA has received much criticism, though the debate surrounding the procedure has itself been seen as a useful discussion of assumptions, and even prejudices (Graf and Komatsu, 1995; Reingold and Toth, 1996; Toth and Reingold, 1996), concerning conscious / unconscious, and explicit / implicit determinants of performance on tests of memory (see also Buchner, Erdfelder and Vaterrodt-Plünnecke, 1995; Roediger, 1994; Rugg, Allan and Wilding, 1995). One particular criticism concerns the use of the independence assumption to model the relationship between recollection and automatic influences of memory. As noted above, under this assumption Jacoby, Toth and Yonelinas (1993) found that an estimate of automatic influences was unaffected by dividing attention, while the estimate of recollection was significantly altered. This, argued the authors, suggests that each basis is functionally independent of the other, as the model assumes.

However, if a different assumption is made for the relationship between recollection and automatic influences, e.g. that each is 'redundant' (i.e. recollected items form a subset of items also associated with automatic influences), then effects of the divided attention manipulation are evident on the estimates of both bases for performance (Joordens and Merikle, 1993; Richardson-Klavehn, Gardiner and Java, 1996). Use of an 'exclusivity' assumption (i.e that both bases for performance never co-occur), leads to another, different, pattern of effects on the estimates which the procedure derives for automatic and recollective influences. As noted by Richardson-Klavehn, Gardiner and Java (1996), this sensitivity to initial assumptions means that Jacoby, Toth and Yonelinas' (1993) results only support the independence assumption if this assumption is made a priori. The argument is thus circular, and the procedure cannot therefore be used to support the independence assumption (but see Jacoby et al., 1994; Jacoby, Yonelinas and Jennings, in press).

The analysis of the PDA provided by Richardson-Klavehn and colleagues raises other pertinent issues. Notably, they point out that the PDA in its present form assumes that explicit retrieval always result from an 'intentional', or voluntary, effort. In contrast, implicit memory always result from an act of incidental, or involuntary retrieval. To see that this is so, recollect that the PDA as described above assumes that automatic influences of memory are never associated with explicit memory. If they were, then on the exclusion task items which come fluently to mind would be excluded on that basis. So according to the PDA, recollection is the voluntary explicit retrieval of studied items. Involuntary recollection is thus oxymoronic. In its present form, the PDA thus makes a kind of transparency assumption between a state of awareness (explicit vs. implicit) and retrieval strategy (intentional vs. incidental). Yet, there is empirical evidence that retrieval strategy and state of awareness are orthogonal. This evidence is discussed in the following sections.

1.3.2 Behavioural Measures of Awareness

1.3.2.1 An 'Off-line' Measure

Schacter and colleagues developed a test-questionaire method of monitoring, off-line post-experiment, whether subjects were aware of the connection betweeen study and test phases of stem completion tasks (Bowers and Schacter, experiment 1, 1990; Schacter, Bowers and Booker, 1989) [3]. The purpose of this work was to verify that significant levels of priming could be obtained in subjects who were unaware of the relationship between the study and test phases of the experiment. This, argued the authors, is functionally equivalent to amnesic patients, who exhibit intact priming on stem completion in the abence of any memorial awareness. To achieve this aim, Schacter et al. had to develop a method of monitoring the awareness of their subjects, to establish whether they were aware or not. The method chosen for this was to employ a post-test, off-line, questionnaire which assessed awareness.

In these studies, subjects first studied single words using a deep and a shallow orienting task (a depth of processing manipulation). At test, subjects either carried out a stem completion or a word-stem cued recall task. Half of the subjects in each test condition were informed of the relationship between the study and test phases (test-informed condition) while the remainder were not (test-uninformed condition). Following the test phase, test-uninformed subjects received a further questionnaire which attempted to find out if these subjects had, through one means or another, become aware of the relationship between the study and test phases of the experiment (including questions such as "Did you at any point during the test phase notice that you were completing stems with words which had been studied?"). The questionnaire thus provided a measure, albeit crude, of the state of subjects awareness during the period in which they were performing the task.

Using the answers provided to the questionnaire, subjects were categorised as either test-aware or test-unaware. Subjects who did not report noticing any connection between study and test phases were test-unaware. A critical finding was that

[3] The same data set is presented in both papers.

significant levels of priming on the stem completion task were observed for both test-aware and test-unaware subjects. Schacter et al. argued that this showed priming can occur independently of explicit memory, as measured by the post-test questionnaire method. The post-test questionairre method thus provided a means of obtaining a pure measure of implicit retrieval.

The test-unaware subjects were also just as likely to complete stems with items studied with the shallow task as the deep task. The depth of processing manipulation thus had no effect on the stem completion performance of these subjects, but did have a reliable effect on the subjects' cued recall performance. Schacter et al. argued that this critical finding was evidence for a difference in the retrieval intentionality of subjects on the stem completion and the cued recall task. Retrieval was intentional on the cued recall task, but incidental on the stem completion task. In contrast, test-aware subjects *were* more likely to complete stems with deeply studied than shallowly studied items on the stem completion task. The depth of processing manipulation thus had parallel effects on the cued recall and stem completion tasks, but only with subjects who were test-aware. Schacter et al. argued that the test-aware subjects may have intentionally retrieved studied items, thus disobeying the stem completion instructions. If correct, this interpretation suggests that in other studies where parallel effects of depth of processing were found on direct and indirect tasks (Brown and Mitchell, 1994), it may be because subjects intentionally retrieved items from the study phase when the task instructions dictated that they should not. If correct, this implies that depth of processing effects on stem completion may not be taken as evidence for the contribution of a conceptual priming component to the task.

However, the above rather sweeping conclusion is not supported by data from Schacter, Bowers and Booker's (1989) test-informed group of subjects. These subjects were by definition test-aware (i.e. they were informed of the relationship between study and test prior to the test). If such awareness leads to the adoption of an intentional retrieval strategy, then a depth of processing effect should have been

evident in the stem completion data for these subjects. However this was not the case. As for the test-unaware subjects, the test-informed subjects were no more likely to complete stems with deeply studied than shallowly studied items. This finding indicates that test-awareness does not always lead to an intentional retrieval strategy. Functional dissociations between stem completion and cued recall may therefore still occur even if subjects are explicitly aware of the connection between study and test phases. If a parallel effect of a manipulation, such as depth of processing, is observed on a direct and an indirect task (e.g. Brown and Mitchell, 1994), then this cannot simply result from the contamination of indirect task performance by explicit retrieval. Rather, the parallel effects may occur because subjects adopt an intentional retrieval strategy on the direct and indirect tasks. The critical difference between direct and indirect tasks may therefore be in retrieval strategy, and not in the state of awareness which accompanies memory retrieval.

Studies by Richardson-Klavehn and colleagues further support this distinction between state of awareness and retrieval strategy. These studies have shown that explicit memory frequently occurs in subjects who have not adopted an intentional retrieval strategy on the stem completion task (Richardson-Klavehn, Gardiner and Java, 1994; 1996; Richardson-Klavehn and Gardiner, 1995; 1996). The studies, which are reviewed below, show that explicit memory and intention to retrieve should be considered as separate theoretical constructs. In addition, the studies introduced an 'on-line' measure of awareness which gets round problems inherent to the off-line measure employed by Schacter and colleagues.

The major problem with the off-line method is not least that it is itself a form of direct test. It requires subjects to think back to study episodes in order to remember whether the occurrence of study items had been noticed. As such, the method could be affected by forgetting. Further, as Schacter and colleagues have noted, subjects need only recollect a study item on a single trial to become test-aware. Thus the method is not sensitive to differences in the level of test awareness, or rather explicit retrieval, which may occur as a function of experimental variables such as study

depth of processing. A more sensitive method of recording the memorial state of awareness of subjects would have to involve some form of on-line measure taken whilst subjects were performing the tasks.

1.3.2.2 An 'On-line' Measure

Richardson-Klavehn and colleagues have developed on-line measures of awareness applicable to variants of the stem completion task (Java, 1994; Richardson-Klavehn, Gardiner and Java, 1994; 1996; Richardson-Klavehn and Gardiner, 1995; 1996; see also Richardson-Klavehn et al., 1994). The purpose of these studies was to develop 'pure' measures of explicit and implicit memory based on contrasts between direct and indirect tasks. In an approach similar to Jacoby and colleagues, Richardson-Klavehn et al. developed a novel variant of the stem completion task, which requires subjects to complete stems with the first word which comes to mind, but to omit those completions which are recognised as having been studied. In order to do this, subjects have to recognise on-line trial by trial whether or not a given completion which comes to mind was a studied item. If the item was studied, then it has to be set aside and another completion has to be generated, which can then be given in response. The basic approach has been to contrast performance on this 'opposition' task, with performance on standard cued recall and stem completion tasks. As detailed below, the authors argue that by comparing performance on the stem completion and opposition tasks, measures of involuntary implicit and explicit memory may be gained.

1.3.2.3 A Final Example

In an initial study (Richardson-Klavehn, Gardiner and Java, 1994; see also Java, 1994 and Richardson-Klavehn and Gardiner, 1995), subjects studied items with a deep and a shallow orienting task (another depth of processing manipulation). At test, subjects carried out either cued recall, stem completion or opposition tasks. An on-line measure of awareness was provided during the opposition task by requiring

subjects to complete stems only with unstudied items. The argument being that if a studied item was given in response to the stem, then this cannot have been associated with explicit memory - else it would not have been given. If the proportion of stems completed with studied items on the opposition task was above the baseline completion rate, this would indicate that significant priming in the absence of explicit memory occurred. The authors made the further assumption that the involuntary tendency to produce studied items on the stem completion and opposition tasks would be identical. However, involuntarily produced items associated with explicit memory will be given in response on the stem completion task, while on the opposition task such items will not be given. Therefore, subtracting opposition task performance from the stem completion task performance should give a measure of involuntary explicit memory. Finally, if stems were completed involuntarily on the stem completion task, then performance should not be sensitive to the depth of processing study manipulation. In contrast, performance on the cued recall task should be sensitive to the study manipulation.

The critical findings from the study matched the account and predictions made above. Thus cued recall, but not stem completion, was enhanced for items accorded deep study. This indicated that subjects did not intentionally retrieve items on the stem completion task, for if they had a depth of processing effect would have been observed. A quite different pattern of effects occurred for the opposition task. In this case there was an inhibitory effect of depth of processing, such that items accorded shallow study were given in response more often than items accorded deep study. This finding is readily interpretable, given that completions with deeply studied items were more often accompanied by explicit memory, and so replaced more often than were shallowly studied items. The proportion of stems completed with shallowly studied items on the opposition task was also significantly larger than the baseline completion rate, indicating a significant influence of memory. Critically, this influence of memory was both involuntary and implicit (Richardson-Klavehn, Gardiner and Java, 1994). Finally, the measure of involuntary explicit memory provided by subtracting performance on the opposition task from the stem

completion task was larger for deeply studied than shallowly studied items. This finding reveals that explicit memory varied with the study manipulation (was increased for deeply studied items) while at the same time the involuntary tendency to complete stems with studied items was invariant across encoding conditions. Thus explicit memory and retrieval strategy (voluntary vs. involuntary) were dissociated.

In a subsequent study of similar design, Richardson-Klavehn and Gardiner (1995) provided novel evidence on the time course of performance on the cued recall, stem completion and opposition tasks. This was obtained by recording the time subjects took to generate a response on each trial. The time measures indicated that the mean response time on stem completion and opposition tasks were essentially identical (at around 4s). In contrast, the mean cued recall response time was around 9s. This data supports the authors' contention that on stem completion and opposition tasks subjects employ different strategies than on cued recall. In particular, the cued recall task may have involved a more effortful and time consuming intentional retrieval strategy. In contrast, the stem completion and opposition tasks may have involved a less effortful involuntary strategy, in accordance with the instructions for each task.

1.3.3 Obtaining a Pure Measure of Memory Retrieval: Summary

Three different methods of obtaining a pure measure of explicit and implicit memory were introduced. Jacoby and colleagues PDA was introduced first. Criticisms of the approach were noted. The estimates of explicit and implicit retrieval derived from the PDA were shown to reflect a mixture of intentional and incidental retrieval. However, the off-line and on-line measures of awareness introduced by Richardson-Klavehn, Schacter and colleages showed that retrieval strategy and state of awareness should be distinguished. Off-line measures using questionnaires given post-test indicated that subjects who were unaware of the connection between study and test phases nevertheless showed significant levels of priming on the stem completion task. The on-line measure developed by Richardson-Klavehn and colleagues also showed that involuntary implicit completions with studied items

occurred more often than chance. In conjunction, both sets of findings show that pure measures of implicit retrieval can be obtained on stem completion tasks. The studies therefore indicate that in normal subjects, significant levels of item specific priming can be observed even when there is no explicit memory for study episodes.

These studies have also shown that large numbers of subjects do become test-aware during performance on stem completion. However, it is not the case that such explicit memory need either result from, or lead to, the adoption of an intentional retrieval strategy, contrary to the stem completion instructions. The use of manipulations such as depth of processing was shown to be suitable as a means of determining when subjects were employing intentional or incidental retrieval strategies on stem completion. If retrieval is intentional, then performance should be sensitive to the depth of processing manipulation, as for word-stem cued recall. If retrieval is incidental, manipulations such as study depth of processing will not affect stem completion performance. Explicit memory is thus not dependent on an intentional retrieval effort.

1.4 The Present Studies

This chapter reviewed a large body of evidence suggesting that it is meaningful to distinguish between different forms of memory according to whether retrieval is accompanied or unaccompanied by awareness. Systems and processing models of memory were introduced as frameworks which attempt to account for the neurological and functional dissociations associated with explicit and implicit retrieval. Studies of stem completion and cued recall tasks were used to introduce the notions of task and process purity, and to illustrate methodological approaches which try to circumvent the problem of task impurity.

Three different approaches to obtaining pure measures of explicit and implicit retrieval were discussed. Problems with the model-based process dissociation

approach of Jacoby and colleages were introduced, and the alternative empirically-based approach of Schacter, Richardson-Klavehn and colleagues were put forward as alternatives. The use of measures of awareness, either during task performance (on-line) or post-test (off-line) in conjunction with behavioural measures of task performance (i.e. number of stems completed with studied items) were sufficient to isolate the contribution of implicit and explicit retrieval to performance in different experimental conditions. Perhaps the best, most sensitive means of investigating the purity of tasks is to introduce 'on-line' measures of awareness during task performance. These measures aim to uncover the circumstances in which explicit memory accompanies task performance, and how this is affected by experimental variables such as the widely-used depth of processing manipulation.

To complement the growing body of research on the neural basis of explicit and implicit retrieval, on-line measures of awareness would ideally distinguish between different forms of memory retrieval in terms of the patterns of brain activity with which they are associated. The event-related potential (ERP) technique used in the studies presented in this thesis involves the measurement of stimulus-locked changes in the electrophysiological state of brain regions involved in processing during task performance. In the initial three exploratory studies presented in the first part of this thesis, ERPs were used to obtain on-line measures of neural activity during performance on a word-stem cued recall and a stem completion task. These three studies attempt to provide a convergent means of assessing whether these tasks are pure with respect to the nature of retrieval underlying performance. The studies also provide a means of assessing whether or not different forms of retrieval can be mapped onto qualitatively different patterns of neural activity, and therefore onto distinct neural circuits, in accordance with predictions of systems models of memory.

The application of ERPs to this area of research represents an extremely interesting, and hopefully fruitful, approach. This is because the ERP technique allows multiple forms of transparency assumption to be investigated. First, the technique allows

investigation of transparency assumptions relating 'process with task'. This is done by determining whether ERP correlates of explicit (or implicit) retrieval are present for both direct and indirect tasks. Second, the technique allows the relationship between a given process and its neural substrate to be investigated under different task conditions.

The remainder of the thesis is organised as follows. The principles of data collection, processing and analysis for the ERP technique are introduced in the following chapter 2. In chapter 3 a review of ERP studies of retrieval from long term memory is presented. Chapter 4 provides a description of methods which are common to all six empirical studies presented in the thesis. The results of the empirical studies are presented in Chapters 5 through 10. Chapter 11 provides a general discussion of the results of all six studies.

2.0 Event-Related Potentials

2.1 Introduction

The transmembrane electrochemical activity of neurons constitutes the primary, and perhaps unique, class of biophysical process on which all psychological function depends (e.g. Churchland, 1986). There are various methods which attempt to record and analyse neuronal activity associated with specific psychological processes. The studies in this thesis employ the event-related potential (ERP) technique to record changes in the electrophysiological state of the brain as information is processed during memory tasks. The ERP technique exploits the properties of electrical fields generated by collections of active neurons. Under suitable conditions, these electrical fields propagate through the conductive media of the brain and its coverings, to reach the scalp. Non-invasive recordings of this activity (constituting the electroencephalogram, or EEG) may thus be obtained via electrodes placed on the scalp.

The ERP technique involves the measurement of changes in the EEG which reflect the neural processing of experimental stimuli. A major advantage of the technique is that it permits the neural activity (or rather, that fraction detectable at the scalp) associated with the processing of different classes of stimuli to be measured, in 'real-time', at a high temporal resolution (in the order of msec). A further advantage of the ERP technique is the ease which measures of brain activity contingent on the nature of the subject's response can be obtained. Such measures, essential for some kinds of cognitive studies (e.g. the analysis of errors) are not easily obtained with neuroimaging techniques based on measures of cerebral blood flow, such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI).

The ERP technique is in fact complementary to these other neuroimaging techniques, which provide a high degree of spatial resolution (in the order of mm) at the cost of very poor temporal resolution, tens of seconds in the case of PET. While recent developments in fMRI offer the prospect of imaging changes in blood flow/volume over much shorter intervals than can be achieved with PET, the response time of the cerebral vasculature (1-3sec) remains a limiting factor. This is arguably too slow, by about two orders of magnitude, to track, in real-time, the neural activity supporting many of the cognitive processes identified by experimental psychologists.

For some decades now a considerable effort has been invested in devising methods of analysing electrical manifestations of brain activity as they present at the scalp. This chapter discusses these methods, and also some general constraints on using ERPs to interpret the functional neuroanatomy of cognition. The following material derives mainly from Allison, Wood and McArthy (1986), Binnie (1987), Coles, Gratton and Fabiani (1990), Nunez (1981; 1990) and Rugg and Coles (1994).

2.2 ERP Electrogenesis

The electrical fields generated by the brain result from changes in the polarisation of individual neuronal cell membranes, which produce localised fields. Studies suggest that the majority of the fields picked up in scalp recordings originate from excitatory and inhibitory post-synapic potentials (EPSPs and IPSPs, respectively). The local fields generated by a number of neuronal elements undergo spatial summation. The resulting summated electrical fields can be classed as either 'open' and 'closed'. This distinction is based upon whether or not the electrical field propagates beyond the limits of the generating structure itself. Open fields can be recorded at a distance, whereas closed fields do not propagate beyond their generator(s), and can therefore only be recorded by electrodes placed within or very near to the generator(s). The EEG does not therefore represent a measure of the total activity of the brain, since only a proportion of the brain's activity ever reaches the scalp.

The type of field which is generated depends critically on two factors. One is the spatial arrangement of the cells making up the generator. Certain arrangements of cells produce local current flows, while others produce current flows which can propagate beyond the generator structure itself. Structures with an open field configuration are arranged such that fields generated by individual cells can summate without mutual interference or cancelling out. An open field configuration is necessary but not sufficient for the generation of open fields.

The other important factor is the temporal synchrony of changes in the polarisation of the individual cells. The magnitude of the fields produced by a generator is affected by the synchrony of the activity of its cells. If the activity of suitably oriented cells is temporally synchronous, this will give rise to a field which will summate and propagate outwith the bounds of the generating structure. Most cell assemblies produce field potentials with both open and closed properties. A principle of 'superposition' governs the summation of electrical fields. The potential recorded at a given point represents the algebraic sum of all fields reaching that point. As open fields pass through the brain and it's coverings, they linearly summate with one another. The resulting scalp recorded EEG therefore reflects the linear summation of fields generated in multiple regions.

The EEG is a record of the difference in potential between two points on the scalp over time, however, multiple electrodes are typically used to sample the spatial distribution of the EEG across the scalp. The voltage potential at each recording electrode is typically measured with respect to a common reference electrode(s). The pattern of EEG seen at each recording electrode is thus a difference measure taken with respect to the reference. Signals which are common to the reference and recording electrodes are therefore cancelled out. Accordingly, the location of reference electrodes is an important aspect of EEG recording.

In each study reported here, linked (i.e. short-circuited) electrodes placed on the mastoid bones behind each ear were used as a reference (see chapter 4, General Methods, and individual method sections, for more details). The 'virtual location' of the reference point which results from this reference is hard to determine (e.g. Picton, Lins and Scherg, 1995), since the amount of activity from each mastoid electrode which contributes to the combined recording will vary as the impedance of each electrode varies. The absolute magnitude and the polarity of the differences recorded at each electrode may thus vary according to the virtual or actual position of the reference electrode. But because the relative position of each recording electrode with respect to the reference remains constant, the shape or 'profile' of the EEG across each electrode does not change even with changes in the position of the reference electrode. In experiments 4, 5 and 6 reported in this thesis (see chapters 8, 9 and 10), separate left and right mastoid channels were recorded. This procedure allowed EEG activity at these channels to be viewed, so as to verify that little or no evoked activity was present, for each individual subject. Once this had been verified, the EEG data were then re-referenced, off-line, to a linked mastoid reference (see method sections of individual chapters for more details).

2.3 ERP Recording

As mentioned above, the ERP technique involves measuring often minute changes in the EEG which reflect the neural processing of experimental stimuli. This is achieved by recording samples of EEG which are time-locked to the onset of some definable event, such as the presentation of a word. The magnitude of the brain potentials associated with such events is typically small in comparison to the amplitude of the background EEG, which is in effect the noise from which the ERP 'signal' has to be extracted. The most commonly employed method of signal extraction is 'averaging'.

Typically, a single epoch of EEG is sampled on each experimental trial. Each experimental condition will have a number of such trials, and therefore epochs, associated with it. Averaged ERPs representing each experimental condition are formed by averaging together epochs from each constituent trial. This gives averaged ERPs for each subject, in each condition, at all electrode sites. Across subject averages, or 'grand average', ERPs can then be formed which represent neural processing accorded to stimuli in each experimental condition across all experimental subjects.

The signal to noise ratio of averaged ERPs will increase proportionally with the square root of the number of trials used to form each ERP. The noise is composed of neural activity which is not evoked by (i.e. not time locked to) the onset of the evoking stimulus. An additional source of noise comes from extra-cerebral artifact, most critically the muscle activity of eye and body movements occurring immediately prior to or during the recording epoch. Suitable methods for the detection and reduction of such artifacts must be employed to ensure that only artifact-free trials are used in the averaging process (see chapter 4, General Methods, for details of such procedures adopted in the current studies).

Across-trial variation in the amplitude of an ERP effect, or in the latency at which it onsets, may make averaged ERPs unrepresentative of the effect on individual trials. Variations in onset latency ('latency jitter') are more critical in this respect. The best method of determining whether such jitter exists is to inspect individual trials to determine the onset latency of a given ERP effect present in the grand averages. However, the low signal to noise ratio of individual trials often makes this form of analysis impossible [4].

2.4 Component-Based Descriptions of ERPs

[4] Analytical methods of quantifying and compensating for the temporal jitter of signals are available (e.g. see Picton, Lins and Scherg, 1995).

Figure 2.1 shows an ERP recorded at the Fz electrode site (the position of this site on the scalp is depicted in figure 4.1, see chapter 4). The x-axis is time, the y-axis is voltage. Time zero is the point at which the stimulus is displayed. The time marker indicates a point 200ms post-stimulus. The peaks and troughs of the waveform shown in figure 2.1 can be conventionally labelled by either their polarity and latency, or their polarity and serial order from stimulus onset. For example, the arrow in the figure points to the P200, or P2 (the second positive peak in the waveform, with a peak latency of approximately 200ms). This convention allows the ERP to be described, but does not give any insight into the underlying processes which determine the shape of the ERP. However, if the ERP waveform is considered as a composite of spatially and temporally overlapping components, then this problem becomes more tractable.

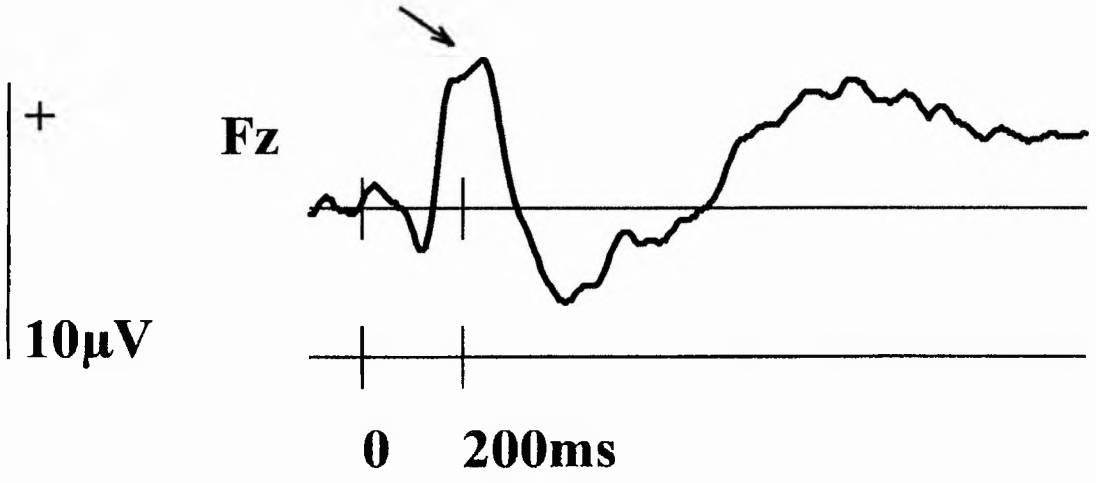


Figure 2.1 ERP recorded from the Fz electrode site. The arrow on the figure points to the P2 / P200, component of the ERP. See text for more details. Data taken from Wilding, 1995, unpublished doctoral thesis. Reproduced with kind permission of the author.

Thus, the activity of the multiple generators of ERPs summate to produce the observed morphology of the scalp recorded waveform. The identification of components with peaks and troughs of the ERP waveform has been questioned on

the grounds that they are not likely to be independent (e.g. Donchin, Ritter and McCallum, 1978). That is, the amplitude of particular peaks or troughs may be correlated with the amplitude of succeeding troughs or peaks, respectively. This implies that care should be taken when identifying a particular peak or trough as reflecting a single component. For example, since scalp recordings reflect the summated activity of multiple generators, the peaks and troughs of an ERP may not coincide with the maximal or minimal levels of activity of any single generator. In addition, the peak latency of a particular feature of the ERP, say the P2 in figure 2.1, may not accurately reflect the timing of an underlying brain process, because of latency jitter across trials.

As a class, component features of the ERP which exhibit sensitivity to the physical form of stimuli have been termed 'exogenous'. In contrast, later 'endogenous' ERP components, as reflected by particular 'late' peaks and troughs of the waveform, are held to largely reflect more complex, higher order cognitive processing accorded to the stimulus. Such components are thus more sensitive to variables considered to affect cognitive processing and the particular demands of given tasks. The distinction between exogenous and endogenous components is meant to reflect a continuum, and is not a dichotomy.

Modulations of either individual or multiple component features can in principle give rise to changes in the morphology of ERPs. These modulations can take the form of changes in latency (or time course), magnitude or scalp distribution. The scalp distribution of individual ERP components is a feature which tends to be more robust. Indeed, a reliable difference in ERP scalp distribution across two experimental conditions indicates 'qualitative' differences in the brain activity which generates the ERPs in each condition (Rugg and Coles, 1994; and see the final section below). Accordingly, the use of scalp distribution as a defining feature of an ERP component depends exactly on how a component is defined. There are two main approaches.

The 'physiological' approach defines an ERP component as that part of the ERP waveform generated by a particular region, or regions, of the brain. Importantly, such definitions do not involve specification of the function of the given region(s). Thus to the extent that neural circuit participates in a number of functions, the same ERP component may occur on a variety of tasks, and be modulated by a number of factors. According to this approach, an ERP component cannot change its scalp distribution, since this would imply (all else being equal) that different brain regions are involved, or that the same regions are active with different relative levels of activation.

In contrast, the 'functional' approach defines ERP components in terms of particular cognitive processes. Regions of the ERP (e.g. particular peaks or troughs) which are sensitive to manipulations of such processes are, in this approach, identified as ERP components. Note that no account is taken here of the neural generators of the ERP component. Under the functional approach, it is conceivable that two or more modulations of the ERP, each with a radically different scalp distribution, could reflect identical functions (see Rugg and Coles, 1994, for a particularly clear example of this).

The physiological and functional approaches to component definition are complementary precisely to the extent that particular cognitive functions are localised to particular neural circuits. But in practice, researchers tend to adopt elements of both approaches in identifying ERP components. For example, as an optimal means of defining the component structure of ERPs, Picton and Stuss (1980) suggested that a number of approaches should be combined, using both physiologically and psychologically based manipulations as a way of defining the sources of variability in ERPs. This practical approach to understanding the component structure of ERPs is illustrated in detail in the following chapter, which introduces ERP studies of memory which bear upon the present work.

In the following final section of this chapter the interpretation of ERP modulations is discussed so as to show how ERPs are used to inform on the functional neuroanatomy of cognition. This final section focuses upon the kinds of interpretation employed in the ERP studies of memory reviewed in the next chapter.

2.5 Functional Interpretations of ERP Effects

The ERP technique is correlational. That is, having identified an ERP effect, it is not possible to state that this effect reflects directly the psychological processes which are under scrutiny. This may indeed be true, but it is also possible that an observed ERP effect reflects processes which are only contingent upon the actual process of interest. This caveat applies to all methods of determining function from recordings of brain activity which do not incorporate the study of lesions to, or inactivation of, the putative source of a given function.

Functional conclusions based upon ERP effects should therefore be made with caution. Such conclusions are in general based upon differences found when comparing ERPs in two or more experimental conditions, given that a suitable statistical test has confirmed their reliability. Different kinds of ERP effects can be observed as a function of experimental conditions. Any difference whatsoever, be it in terms of amplitude, latency, or scalp distribution of an ERP component, indicates that the neural processing of evoking stimuli was not identical across conditions. However, the absence of any difference between ERPs across experimental conditions does not imply that neural processing was identical in each case. Remember that scalp recorded ERPs do not reflect the totality of brain activity. Accordingly, there may be differences in the neural processing of stimuli as a function of condition which never give rise to a detectable scalp signal. Similarly, the onset latency of an ERP effect does not approximate the point in time at which neural processing begins to differ. Rather, the onset latency of the effect determines an upper bound on the time at which processing differs, albeit with a millisecond resolution. Differences in the amplitude, latency and scalp distribution of ERP

effects are the basis of the functional interpretations given in the studies comprising this thesis. The interpretation of such differences forms the basis of the ERP studies of memory which are reviewed in the next chapter. The basis for such interpretations is discussed below.

It is not difficult to determine whether ERPs from two or more experimental conditions reflect qualitatively different patterns of brain activity. This is accomplished by 'topographic analysis' of ERPs recorded from a number of electrode sites. Significant differences in the topography of ERPs across conditions constitute the necessary basis for postulating qualitative differences in brain activity. Such qualitative differences may be interpreted in two different ways. Qualitatively different scalp ERP effects can arise if *different brain regions* contribute to each effect. Alternatively, identical regions may be activated in each condition, but with *differing levels of relative activation.* Note that each interpretation involves the assumption that multiple brain regions contribute to the ERP effects. The presence of such qualitative differences is a necessary, but not a sufficient, condition for the postulation of functional differences in the processing engaged as a function of experimental condition or over time (Rugg and Coles, 1994).

However, determining the intracerebral location of the generators of an ERP effect is not an easy task. In principle, there is no unique solution to this problem, since a particular scalp field may be generated by an indeterminate number of different configurations of intracerebral sources (the so-called 'inverse problem'). The studies reported in this thesis do not attempt to explicitly map ERP effects and intracerebral sources. But some studies (see chapters 8, 9 and 10, experiments 4, 5 and 6) do use topographical information to make inferences about the neural generators of ERP effects. Chapter 4 explains the topographic analyses which were used in these experiments.

Differences in the amplitude or latency of an ERP component, in the absence of differences in scalp distribution, may be taken as evidence for the engagement of similar brain regions which are differentially activated, across conditions. Generally,

differences in the amplitude or latency of a particular feature imply 'quantitative' effects upon underlying brain activity within similar regions, activated in each condition. In contrast, differences in the scalp distribution of ERPs across conditions (or within a single condition, but across selected latency windows) suggests a qualitative difference in brain activity, as noted above.

The functional interpretation of pure amplitude or latency effects (i.e. quantitative differences between ERPs per condition) begins with the acknowledgment that similar cognitive processes are probably engaged in each condition. Next, consideration must be given to the electrophysiological events which can give rise to such quantitative effects. Differences in amplitude between conditions may have a number of different causes. Significant latency jitter across individual trials comprising an averaged ERP waveform may give rise to the 'temporal smearing' of an ERP component, resulting in the reduction of it's size, and its apparent latency. In such a case, a functional interpretation the amplitude / latency modulation may invoke differences in the distribution of the time course of cognitive processes across two conditions.

Alternatively, amplitude modulations may reflect genuine experimentally induced 'quantitative' changes in the activity of a given generator circuit. Such amplitude modulations must result from either changes in the amount of input (extrinsic or intrinsic) to cells within the generator, or changes in the synchrony of inputs. Increased synchrony of input would give rise to larger fields resulting in greater amplitude of an effect at the scalp, and vice versa [5]. In this case, a functional interpretation of the amplitude modulation must depend on how changes in the activity of the generator circuit relate to the function which it instantiates. Hence, it is not obvious that a general rule can be applied to the interpretation of amplitude modulations in such a case. The studies reviewed in the following chapter provide some examples of how differences in the amplitude an ERP effect are interpreted in terms of changes in the cognitive processing of stimuli.

[5] I emphasise input because it is EPSPs and IPSPs, generated by inputs, which are largely reflected by scalp recordings.

3.0 Event-Related Potential Studies of Retrieval from Long-Term Memory

3.1 Introduction

For the last half decade or so, a large part of the research from the St Andrews ERP laboratory has been devoted to studying ERP 'old/new' effects (see below) observed on direct tests of memory (mainly recognition memory for verbal materials). The aim of this research has been to relate what is known of the functional neuroanatomy of explicit memory to ERP correlates of performance on such tasks. In conjunction with the findings and conclusions from studies produced by a number of other laboratories, it seems clear that ERP old/new effects can provide a means to study neural processing associated with explicit retrieval. There are also some recent indications that ERPs may in addition reflect the activity of 'working-with-memory systems (e.g. Moscovitch, 1994; and chapter 1) involved more with the 'on-line' use of retrieved information than in retrieval processing which supports recognition judgments.

The studies presented in this thesis are a direct extension of this previous work relating ERPs and explicit memory. Therefore, to provide a context for the present studies, a review is presented below of a range of different approaches to the study of ERPs and explicit memory. The studies reviewed below range from investigations of ERP correlates of performance on tests which operationalise what it means to 'recollect' information (e.g. Wilding and Rugg, 1996), to studies which have employed ERPs to investigate whether indirect tasks are contaminated by explicit memory (e.g. Paller and Kutas, 1992). An additional aim of the review is to emphasise the variety and flexibility of the ERP approach to this area of cognitive psychology. The review shows how improvements in experimental methodology (for example in the use of operational definitions of recollection, and increasing the

duration of ERP recording epochs) have been critical to progress in understanding what ERPs may reveal about the neural basis of explicit memory.

3.2 ERPs and Explicit Retrieval: Direct Tasks

The basic logic of all the ERP studies to be discussed below is as follows. Each study contrasts ERPs evoked by stimuli presented in different experimental conditions. Any differences in the ERPs evoked, as a function of condition, are then interpreted in terms of the presence, absence or modulation, of cognitive processes engaged in each condition. Without exception, the critical ERP contrasts involve conditions where stimuli are presented either for the first or the second time in the context of an experiment. The difference between the studies lies in how the subject is to treat the fact that items are repeated. Basically, the repetition of a stimulus is either integral to performance, or is incidental to performance. This distinction maps quite well (but perhaps not perfectly) onto that between direct and indirect tasks discussed in chapter 1.

ERPs have been used to study the neural processing accorded to stimuli on direct and indirect tests of memory. These studies have only recently begun to draw upon the database of knowledge, reviewed in chapter 1, on the memory processes involved in performance on such tasks. This is probably because a specific link between ERPs and explicit memory, as measured by direct tests of memory, was first suggested only in 1989 (Smith and Halgren, 1989). Smith and Halgren recorded ERPs while subjects carried out a recognition memory task. This was not the first ERP study of recognition memory, but ERP effects observed in the previous studies were generally interpreted as modulations of the P300 ERP component, which is not considered to be specifically related to explicit retrieval.

Since the majority of the studies to be discussed have employed tests of recognition memory, I will briefly go over the different response categories on the task.

Recognition memory tasks assess the ability to discriminate between items presented for the first time in the context of an experiment ('new' items), and items which have been seen previously ('old' items). The detection of item repetition is thus an integral part of the recognition task. If a given item is judged to have been presented earlier, then the subject has to indicate this by giving some appropriate response, typically pressing a button or saying 'old'. For items presented for the first time, subjects respond 'new'. For each kind of stimulus (old or new), either a correct or an incorrect response can be given. Correct responses to old and new items are termed 'hits' and 'correct rejections', respectively. Incorrect responses are termed 'misses' and 'false alarms', respectively. In some studies mentioned below, performance has been such that ERPs can be formed for all four response categories, though this is not always the case.

3.2.1 The ERP 'Old/New Effect'

The typical ERP effect observed on tests of recognition memory takes the form of a parietally distributed, asymmetrical (left greater than right) positive-going shift in ERPs evoked by hits (old items correctly endorsed as such) relative to correct rejections (new items correctly endorsed as such) (see figure 3.1, overleaf). This effect typically onsets around 300-400ms post-stimulus, and can persist for anywhere between 300ms to 1s. This effect will hereafter be termed the left parietal ERP 'old/new effect'. Critically, ERPs appear to be sensitive to item repetition on tests of recognition memory *only if* the repeated item is recognised as such. That is, the old/new effect, as described, is not observed in ERPs to false alarms or misses (e.g. Neville et al., 1986, Wilding, Doyle and Rugg, 1995). Such findings suggest that the old/new effect may be a reflection of processes mediating recognition memory (Rugg, 1994).

It is worth emphasising the importance of the findings that old/new effects are not observed in ERPs to false alarms and misses. If the old/new effect merely reflected an 'old' decision, rather than a 'new' decision, then it should be present in false

alarm ERPs. Similarly, if the old/new effect was a correlate of processes sensitive to the mere repetition of the item at test, then it should be present in miss ERPs, where the evoking stimulus is a repeated, but forgotten, old item. These two alternative 'functional' explanations of the old/new effect can be discounted on the basis of the findings for false alarm and miss ERPs (see also Rugg, Brovedani and Doyle, 1992).

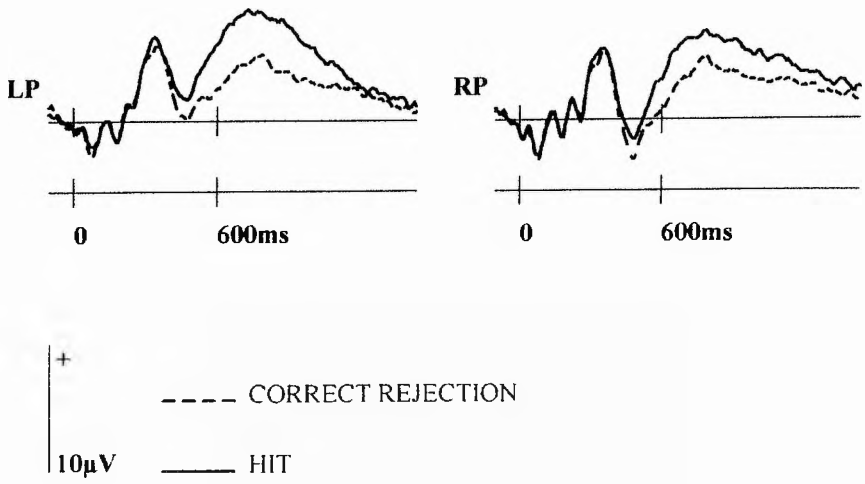


Figure 3.1 The 'Left Parietal ERP Old/New Effect'. The ERPs were recorded at left and right parietal electrodes (Lp and Rp, respectively). The solid line is for hit ERPs (those evoked by correctly recognised old items). The dashed line is for correct rejection ERPs (those evoked by correctly rejected new items). A positive-shift in hit ERPs is evident from around 400ms until 1000ms (see text for more details). Data taken from Wilding, 1995, unpublished doctoral thesis. Reproduced with kind permission of the author.

3.2.2 'Old/New' Effects and the P3b ERP Component

In early studies of ERP effects on tests of recognition memory (e.g. Sanquist et al., 1980; Karis et al., 1984; Johnson, Pfefferbaum and Koppell, 1985; Neville et al., 1986), old/new effects were interpreted in terms of the functional properties of the

P300 (i.e. P3b) ERP component. This widely-studied endogenous component is known to be sensitive to certain 'cognitive' factors (for review see Donchin and Coles, 1988). In particular, the amplitude of the P3b is inversely related to the relative frequency of the classes of stimuli which evoke it. Infrequent events, such as the presentation of a high pitched auditory tone in a series of low pitched tones, elicit a larger P3b. The peak latency of the P3b also increases with the time which subjects require to categorise stimuli (and hence generate a correct response). Finally, the P3b is maximal at midline centro-parietal electrode sites, and diminishes more or less symmetrically with distance from the midline.

There are a number of reasons why the old/new effects observed on tests of recognition memory cannot be considered as modulations of the P3b component. Therefore, functional accounts of the old/new effect cannot reduce to, or take advantage of, functional accounts of the P3b. At least not in any straightforward or obvious manner. Firstly, the typical scalp distribution of the old/new effects observed on recognition memory tasks appears to differ from that of the P3b (Smith and Guster, 1993). Although each is parietally maximal, the old/new effect is both asymmetrical and typically larger at lateral electrodes than on the midline. In contrast, the P3b is typically largest over the midline, and diminishes symmetrically with distance from the midline. Second, it is not at all clear that the hit and correct rejection conditions in a test of recognition memory differ in terms of the factors known to modulate the P3b. That is, it is typical practice for old and new items to be equated in probability of occurrence on tests of recognition memory. More importantly, the response probabilities, i.e. the number of old and new responses made by subjects, are also often more or less equivalent. Thus, hit and correct rejection conditions do not in general differ in terms of their relative frequency of occurrence within an experiment. In conjunction, these two factors, i.e. differences in scalp distribution, and functional properties, are most critical in rejecting a simple correspondence between the P3b and the old/new effect.

A recent study by Smith and Guster (1993) has shown that reliable old/new effects differentiate hit and correct rejection ERPs when the probability of responding 'new' is much lower than that of responding 'old' (0.2 vs. 0.8). If the old/new effect and the P3b reflected functionally identical processes then under these conditions the effect should have been reversed. That is, it should have taken the form of a positive shift in the correct rejection ERPs with respect to the hit ERPs. This was not observed. While Smith and Guster's study did indicate that a P3b modulation occurred on the test of recognition memory, this 'probability effect' could be differentiated topographically from a temporally overlapping memory-related effect which was also present for hit ERPs. The memory-related effect was much more widespread topographically, and also temporally, than the P3b effect. Unfortunately, Smith and Guster only recorded ERPs from three sites situated on the scalp midline, and neglected to record from lateral electrode sites. Therefore, differences between the P3b and the memory-related effect in terms of their hemispheric symmetry could not be assessed. There is a need for a study which distinguishes between the P3b and the old/new effects observed at lateral electrode sites. The P3b-based interpretation of old/new effects will not be discussed any further.

3.2.3 'Old/New' Effects and Recollection

Smith and Halgren (1989) were the first to provide an interpretation of old/new effects in terms of processes postulated within models of recognition memory. Briefly, 'dual process' theories of recognition memory posit that there exist two independent bases for accurate recognition memory judgements; subjects may either explicitly recollect the prior occurrence of an item, or if unable to recollect, the subject may consider the item 'familiar', and then attribute that familiarity to the possibility that the item had recently been experienced (e.g. Jacoby and Dallas, 1981; Mandler, 1980; 1991). The relationship between familiarity and explicit / implicit memory is unclear (e.g. Mayes, 1992). However, it is widely accepted that of the two bases for recognition, only recollection provides contextual information regarding study episodes. Thus, whether properly considered as an explicit or an

implicit form of memory, familiarity is an acontextual basis for recognition (e.g. Jacoby and Kelley, 1992). In any case, Smith and Halgren's (1989) study, described below, prompted much research on the functional nature of ERP old/new effects.

Smith and Halgren (1989) compared ERPs and behavioural performance in three groups of subjects on a study-test recognition memory task. Subjects comprised groups of left and right anterior temporal lobectomy (L-ATL / R-ATL) patients, and age and education matched controls. The effects of repetition on ERPs and performance were measured by repeating the same 10 words throughout 9 blocks of test trials. 10 new words were presented in each block. For controls, an old/new effect was obtained when comparing ERPs for correctly recognised old and new words. Whereas no change in this old/new effect was observed as a function of increasing the number of repetitions, recognition accuracy did increase with repetition. ERPs and behavioural measures from the R-ATL subjects showed an identical pattern of results. In contrast, the L-ATL patient ERPs did not show an old/new effect, but their task performance did improve with item repetition.

Given the lack of a behavioural deficit in L-ATL patients, Smith and Halgren suggested that these patients were relying more than the other subject groups upon perceptual fluency (and hence item familiarity) to make recognition judgements. In contrast, the ERP old/new effect was interpreted as a reflection of processes contributing to recognition based upon recollection. Two distinct components of the old/new effect were identified by Smith and Halgren. The 'early old/new effect' took the form of a modulation of the N400 component (Kutas and Hillyard, 1980), which had a centro-parietal scalp distribution. The magnitude of this negative-going component was found to be reduced in ERPs evoked by repeated items, relative to ERPs to the first presentation. The 'late old/new effect' was as described above: i.e, a positive-going shift in ERPs for recognised repeated items, with a left greater than right, parietal distribution. Thus, in terms of scalp distribution, and time course, the early and late old/new effects were dissociable.

Smith and Halgren gave the early and late old/new effects different functional interpretations. The N400 modulation was held to reflect systems responsible for integrating the semantic attributes of presented words with the subjects ongoing 'cognitive context' to form an episodic memory trace. The late old/new effect reflected functional properties of processes involved with the retrieval of such episodic memory traces. The entire old/new effect (early plus late) is then a combination of the N400 not occurring (because the repeated item has already been presented within the context of the experiment) and an enhancement of a later positive component. Smith and Halgren's ideas thus link only the late positivity with processes responsible for the recollection on which recognition judgements may be based.

The early and late old/new effects can also be dissociated by manipulating the lag inbetween first and second presentations of items. For example, Rugg and Nagy (1989) found that after a delay of 45 minutes, only the later positive shift was present. The early old/new effect is thus only sensitive to item repetition when the delay between study and test is relatively short. On these grounds, and on the basis of the differing scalp topographies and time courses of the two effects, the study of the functional basis of the early and late old/new effects has diverged into two separate areas of research which have relatively little to say to one another at the moment (Rugg and Doyle, 1994). In the remaining studies to be discussed below, the functional nature of the late old/new effect was investigated. Hereafter, the late old/new effect is simply referred to as the old/new effect. The early old/new effect is more commonly refferred to as the 'ERP repetition effect' (e.g. Rugg and Doyle, 1994).

Rugg and Nagy (1989) did not favour the dual process account of recognition memory as a basis for interpreting old/new effects. Never one to rest on his laurels, this did not stop Rugg (1990) from explaining his finding of a dissociation in ERPs to repeat presentations of low and high frequency words in terms of the familiarity process invoked by dual process models (see above). Rugg found that old/new

effects were present only for low frequency items. He suggested that the old/new effect may be sensitive to the level of a words relative familiarity, since repeated low frequency words should have higher relative familiarity than repeated high frequency words (Mandler, 1980; Mandler, Goodman and Wilkes-Gibbs, 1982).

Initial debate following Smith and Halgren's study thus centred around whether the old/new effect reflected 'recollection' or 'familiarity'. The results of a batch of studies produced by Rugg and colleagues (e.g. Rugg and Nagy, 1989; Rugg, 1990; Rugg and Doyle, 1992; Potter et al., 1992) were used as evidence for a familiarity based interpretation of the old/new effect. The results of these studies have since come to be reinterpreted by the authors, in light of more recent work in which operational definitions of recollection have been used to investigate the nature of the old/new effect. Generally speaking, two different approaches to this have been employed to date. These are reviewed in turn in the following sections.

3.2.4 R/K Recognition Tasks

One of the first ERP studies to test the recollection-based interpretation of the old/new effect employed Tulving's 'R/K' procedure (Tulving, 1985). This procedure asks subjects to introspect on the experiences accompanying their recognition decisions. Specifically, subjects are asked to indicate, on each test trial, whether they can *recollect* a specific aspect of the episode in which old items were initially presented, in which case they are to give an 'R' response. Or in the absence of a specific recollection, they nonetheless *know* that the item had been studied, in which case a 'K' response is to be given (see Gardiner and Java, 1990, 1993, and Rajaram, 1993 for reviews of studies employing the R/K procedure).

Smith (1993) contrasted ERPs evoked by correctly rejected new words, and correctly recognised old words which were accompanied by R and K responses. He found that with respect to correct rejection ERPs, both R and K ERPs were the more positive-going. The only difference between the ERPs for R and K responses was that the

old/new effect for R responses was significantly larger in magnitude compared to that for K responses. These findings indicate that the magnitude of the old/new effect is sensitive to whether or not subjects recollect specific aspects of a study episode. Thus, Smith concluded that the old/new effect reflected processing associated with recollection. However, the fact that the K response category was also associated with an old/new effect mitigates the force of Smith's conclusion. If it is the case that the old/new effect reflects the recollection of prior episodes, then why did it occur, albeit in a reduced form, for K responses? Such responses are supposedly defined by the absence of recollection. Therefore, an ERP effect putatively associated with recollection should not be observed for such responses.

A suggestion put forward by Rugg and colleages (Rugg, Wells and Doyle, unpublished manuscript, cited in Rugg, 1994) goes some way towards answering the above conundrum. Rugg and colleagues suggested that the R/K distinction does not completely segregate responses into recollected and unrecollected categories. The same point has been made by other researchers, on different grounds (e.g. Knowlton and Squire, 1995). K responses may reflect a 'weaker' form of recollection, but mediated by processes which also mediate R responses. This account implies that ERPs are sensitive to variations in the amount or quality of information which can be recollected, as reflected by larger parietal old/new effects for R than K responses. To test this notion, Rugg et al. (1995) carried out a study in which words of high and low normative frequency in the language were presented at study and at test. Items of lower frequency in the language are known to be better recognised than items of higher frequency (the word-frequency effect, for discussion see Mandler, Goodman and Wilkes-Gibbs, 1982 and Gardiner and Java, 1993). The reason for this effect seems to be that low frequency items are better, or more often, recollected (e.g. Gardiner and Java, 1993).

Rugg and colleagues employed an operational definition of recollection which was different to that inherent to the R/K task. In their study, subjects were required to assign recognised old items to the context in which the items were presented at

study. The contextual manipulation involved studying items in two word-lists, presented in two different rooms. ERPs were contrasted for conditions where recognised low and high frequency items were correctly and confidently assigned to their study context. Items which could be recognised and assigned to context were defined as having been recollected. A parietal old/new effect was observed for both low and high frequency recollected items, relative to correct rejection ERPs. Critically, the parietal old/new effect was larger for recollected low than high frequency items. Rugg et al. attributed the difference in the magnitude of the effect to differences in the amount or quality of information recollected as a function of the frequency of the old item. Too few trials were available to form ERPs for correctly recognised items which could not be assigned to their study context. The next section details more studies employing the type of approach initiated by Rugg et al.

3.2.5 Source Memory

Perhaps the best evidence linking ERP old/new effects and recollection comes from studies of 'source memory' (Johnson, Hashtroudi and Lindsay, 1993; and see chapter 1). On the basis of having recollected a study episode, it should be possible for subjects to correctly discriminate further aspects of the information presented therein. This definition of recollection as episodic retrieval provides a means of developing an operational measure of recollection, by requiring subjects to make specific 'source' judgments for items which they endorse as old. Source judgments thus assess the ability to correctly place old items in their particular study context. Such tasks are therefore a kind of cued recall task, employing the test item as a retrieval cue which 'specifies' a particular episode from which further information must be retrieved. The task employed by Rugg et al. (1995), described in the section above, is an example of a source memory task.

The fundamental point of using a source judgment to operationalise recollection is that in order to perform the judgment above chance, details of the specific presentation episode have to be recollected. A further assumption inherent to the

approach is that the ability to recollect the prior occurrence of the item per se (i.e. to judge whether the item is 'old' or 'new') is not a sufficient basis on which to make the source judgment. This is possibly because the information on which the source judgment depends is not presented at test. This information must be retrieved with the aid of the test item.

Studies of recognition tasks modified to include a source judgment have been successfully employed to investigate the nature of the processes generating old/new effects (Johnson, Kounios and Nolde, in press; Senkfor and van Petten, 1995; Wilding, Doyle and Rugg, 1995; Wilding and Rugg, 1996, Wilding and Rugg, in press; Wilding and Rugg, submitted). The first published studies were carried out by Wilding and colleagues in the St Andrews Labs. The original purpose of these experiments was to investigate whether the old/new effects reflected recollection or familiarity. As well as clarifying this debate, Wilding et al. have also shown that a novel ERP effect, the 'right frontal old/new effect', may provide further insight into recollective processes.

Wilding and colleages ERP studies have assessed source memory for the modality in which items were presented at study (auditory or visual) (Wilding, Doyle and Rugg, 1995), for whether or not items were presented in a male or a female voice (Wilding and Rugg, 1996), and for whether items were presented auditorially ('heard') or generated by the subject ('spoken') (Wilding and Rugg, submitted). In each study, ERPs were elicited at test for conditions where correctly recognised old items attracted correct (hit-hit ERPs) or incorrect (hit-miss ERPs) source judgments. The hit-hit and hit-miss ERPs were then contrasted with one another, and with ERPs evoked by correctly rejected new items. Across the studies, left parietal old/new effects were observed for both hit-hit and hit-miss ERPs. Critically, the magnitude of this effect was observed to be larger for hit-hit than hit-miss ERPs (Wilding and Rugg, 1996). The change in the magnitude of the left parietal old/new effect was thus predictive of the success of the source judgment.

In addition to the parietal old/new effect, Wilding and Rugg also described a frontal old/new effect, which was larger over the right than left hemisphere. The hemispheric asymmetry characterising the frontal effect onset rather later than the parietal old/new effect, at around 1100ms post-stimulus (Wilding and Rugg, 1996). The use of a 1434ms recording epoch in this study thus provided more information than was available in the previous initial study of source memory (Wilding, Doyle and Rugg, 1995), where a recording epoch of just under 1s was employed. As for the parietal effect, this 'right frontal effect' was present for both hit-hit and hit-miss ERPs, but larger for the hit-hit ERPs (see figure 3.2).

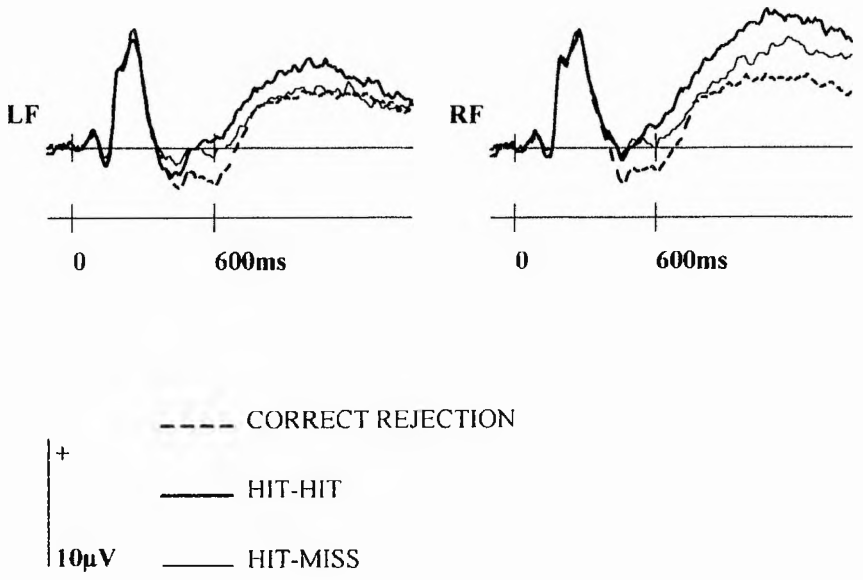


Figure 3.2 The 'Right Frontal ERP Old/New Effect'. ERPs were recorded at left and right frontal electrodes (LF and RF, respectively). The thick solid line is for hit-hit ERPs (those evoked by correctly recognised old items assigned to their study context). The thin solid line is for hit-miss ERPs (those evoked by recognised old items not assigned to their study context). The dashed line is for correct rejection ERPs (those evoked by correctly rejected new items) (see text for more details). Data taken from Wilding, 1995, unpublished doctoral thesis. Reproduced with kind permission of the author.

The parietal and frontal old/new effects were thus dissociable in terms of their scalp topography and their time course. These findings indicate that the two effects are generated by qualitatively different patterns of neural activity, which may result from the contribution of different neural generator structures to each effect. Two independent studies coming from other laboratories have supported the findings reported by Wilding and colleagues. In a study of source monitoring carried out by Johnson, Kounios and Nolde (in press) frontally distributed effects were observed to differentiate ERPs evoked in a recognition task and a source memory task. Similar findings were reported in a study by Senkfor and van Petten (1995) contrasting ERP correlates of performance on tests of item recognition and source memory.

3.2.6 Functional Interpretations of Parietal and Frontal 'Old/New' Effects

3.2.6.1 The Parietal Old/New Effect

The interpretation of the parietal and frontal effects given by Wilding and Rugg drew upon the notion of central 'working-with-memory' systems and 'dedicated memory modules' advanced by Moscovitch and colleages (see chapter 1). Wilding and Rugg argued that the generators of each effect played some role in the recollection of information from the study episode. The increase in the magnitude of the parietal effect may for example indicate that correct source judgments are correlated with the retrieval of more information from the study episode. This fits with the interpretation of Rugg et al. (1995), given above, that parietal effect magnitude may vary with the amount or quality of retrieved information. As I understand it, more specifically, Wilding and Rugg's interpretation appears to be as follows. The parietal old/new effect is an electrophysiological correlate of 'successful' interactions between the medial temporal lobe memory system and cortical regions which 'store' episodic memory traces.

As noted in chapter 1, one possibility which has been suggested is that the medial temporal lobe output acts to synchronise reactivated patterns of neuronal firing across multiple regions of cortex involved in the encoding of information during study episodes (e.g. Damasio, 1989a,b; Damasio and Damasio, 1994). This suggestion is quite interesting from the point of view of ERP effects, since it is just such synchronisation of activity which could be expected to give rise to far field ERP effects in cortical structures with an 'open-field' configuration (see chapter 2).

The interpretation of the parietal old/new effect also receives support from studies of temporal lobectomy patients employing recognition memory tasks (Rugg et al., 1991; Smith and Halgren, 1989). As noted above, Smith and Halgren observed that old/new effects were eliminated in their left anterior temporal lobectomy group. Similar findings were also reported by Rugg et al. (1991). Studies employing depth recording electrodes placed in the medial temporal lobes have also reported ERP components locally generated which are sensitive to item repetition on tests of recognition memory (e.g. Heit, Smith and Halgren, 1990; McCarthy et al., 1989; Smith, Stapleton and Halgren, 1986). The time course of these medial temporal lobe ERP old/new effects is similar to that of the old/new effect recorded by scalp electrodes. In a recent study of epileptic patients, Guillem et al. (1995) also reported that damage to extra-temporal, frontal and parietal regions, was associated with the elimination of old/new effects recorded from depth electrodes placed within the medial temporal lobes. This finding was interpreted as reflecting the interaction of these regions with the medial temporal lobe memory system in the generation of the local old/new effects.

3.2.6.2 The Right Frontal Old/New' Effect

Wilding and Rugg (1996) associated the right frontal effect with the operation of 'working with memory' processes, possibly instantiated by the frontal lobes, which are more critical to the ability to retrieve contextual information for past episodes using test items as cues. The frontal effect was thus seen as a correlate of working-

with-memory processes which may operate with retrieved information to allow further more fine grained discriminations about study episodes. According to Moscovitch's (1994) formulation, a critical aspect of such working-with-memory processes is that they are under strategic, voluntary control, and are not an obligatory consequence of retrieval. The particular function ascribed by Wilding and Rugg to the frontal old/new effect was that it reflected the integration of disparate retrieved information into a coherent explicit representation of previous study episodes.

There are certain critical aspects of the interpretation of the frontal old/new effect. It reflects 'post-retrieval' processing in addition to that necessary for old/new judgments. This post-retrieval processing operates selectively with retrieved information to 'integrate' information which has already been explicitly retrieved (i.e. recollected). The processing is therefore contingent upon recollection. This processing is intentionally engaged in response to the task demand to discriminate source attributes. This final point implies that the processing reflected by the right frontal effect is not an obligatory consequence of recollection, since it is only engaged if there is a specific task requirement to discriminate the source of recollected information.

The final point above is supported by a recent study of associative recall by Rugg et al. (in press(b)). At study, word-pairs were presented. At test, single old and new words were presented, and initially an old/new judgment was to be made. For items endorsed as old, subjects had to retrieve the paired word from the study episode. This is a quintessential recollection task, requiring subjects to utilise the presented word to retrieve the word it was paired with during a specific prior episode. ERPs for correct recognition accompanied by correct recall did exhibit a parietal old/new effect, but a frontal effect was not observed. Given that correct recall of paired items from the study phase was mediated by recollection, it seems very clear that recollection, so defined, is not a sufficient condition for the frontal effect.

3.2.6.3 The Right Frontal 'Old/New' Effect: Now You See It, Now You Don't

The account of the parietal and frontal old/new effects was developed in subsequent studies (Wilding and Rugg, in press; Wilding and Rugg, submitted). In particular, Wilding and Rugg (submitted) showed that changes in the magnitude of the parietal effect could occur without any concommittant changes in the magnitude of the frontal effect. This finding adds further strength to the claim that the underlying processes reflected by each component can operate somewhat independently of one another. Given that variation in the magnitude of the parietal effect reflects attributes of retrieval processing, the lack of such variation in the right frontal effect indicates that it is not related simply to retrieval processes. A similar conclusion was drawn by Wilding and Rugg (in press), based on their study of a recognition memory 'exclusion task', first introduced by Jacoby and colleagues (e.g. Jacoby and Kelley, 1992; and see chapter 1).

Wilding and Rugg's (in press) exclusion task required subjects to only judge an item as 'old' if it had been presented at study auditorially in a particular male or female voice. Studied items presented in the excluded voice were to be judged as 'new', as were genuinely new items. Correctly recognised old items were thus separated into 'target' and 'nontarget' categories, for which different responses had to be made. Critically, as in Wilding and Rugg's (1996) previous study of source memory, subjects in the exclusion task have to discriminate the gender of speakers voice at study in order to correctly exclude nontarget items. Thus, ERPs for those old items correctly assigned to their category, target or nontarget, would be expected to show a left parietal and a right frontal effect. Target and nontarget ERPs both exhibited reliable parietal old/new effects. However, only target ERPs showed a right frontal effect. This finding indicated that although the voice for nontarget items was correctly discriminated, ERPs for this category did not exhibit a right frontal effect. The processes reflected by the right frontal effect are therefore not necessary for the accurate discrimination of source information. This finding argues against the functional interpretation of the effect given above, which specifically links it to post-

retrieval processes acting to cohere or to integrate retrieval products to allow source discriminations.

If the given interpretation of the frontal effect is to be maintained, it would be necessary to postulate that the post-retrieval integrative processes vary according to the status of test items as targets or nontargets (Wilding and Rugg, in press). One possibility is that target items received somewhat more processing prior to the emission of a response, perhaps because a stricter response criterion was adopted for targets. However in the studies to be discussed below, further difficulties for the interpretation of the frontal old/new effect are reported. Notably, this effect has been observed for conditions where there is no overt task requirement to make source discriminations.

Right frontal old/new effects have been observed in studies of memory which do not include an overt source discrimination component. These occurred in an experiment employing an associative recognition paradigm (Donaldson and Rugg, submitted). In Donaldson and Rugg's studies, subjects were first presented with word pairs (e.g. TABLE-PENCIL, DOG-STAR), and then at test were asked to discriminate old from new word-pairs. In experiment 1 only, for pairs judged to be old a further judgment was required. This involved deciding whether recognised old pairs had been initially presented with one another (same pair), or in a different (re-arranged) pairing (e.g. TABLE-STAR). In experiment 2, subjects were only required to make an old/new judgment, with no additional pair discrimination. In each study, parietal old/new effects were observed for both same and rearranged pairs which were correctly endorsed as old, relative to correct rejection ERPs (i.e new pairs correctly endorsed as such). Furthermore, the magnitude of the parietal effect was larger for recognised same than rearranged pairs in each study. However only same pairs were associated with a right frontal effect, and this was observed in both studies. The frontal effect thus occurred i) irrespective of whether subjects were asked to make the same/rearranged pair judgment, and ii) only occurred for same pairs, though rearranged pairs were correctly endorsed as such.

Donaldson and Rugg's finding that only correctly judged same pairs elicited a right frontal effect resembles that of Wilding and Rugg (in press), who observed that only correctly judged target items, and not nontarget items, elicited a frontal effect. Furthermore, in each study the magnitude of the parietal effect was significantly reduced for those items which did not elicit a right frontal effect. This pattern of findings from both experiments suggests a qualitative difference in the processes associated with correct discrimination of the attributes of same / target and rearranged / nontarget items. Donaldson and Rugg's data also strongly suggest that the frontal effect is not contingent upon a task requirement to discriminate source information.

These data suggest that one aspect, at least, of the interpretation of the frontal effect is wrong. Namely, that this effect reflects a *voluntarily engaged* strategy to specifically perform source discriminations. This must be incorrect, because Wilding and Rugg's (in press) exclusion data showed that the frontal effect does not occur in a condition where correct source discrimination is made (for the nontarget ERP condition), and Donaldson and Rugg's data suggest that a task does not even have to require a source discrimination in order to elicit a right frontal effect. The effect may therefore reflect processes acting to cohere or integrate retrieval products, but this process is not specifically engaged by source tasks.

3.2.7 ERPs and Direct Tasks: Summary

The study of 'old/new' ERP effects has revealed multiple processes involved with explicit memory. These processes manifest in ERP effects with different scalp distributions (e.g. the parietal old/new effect, and the frontal old/new effects) and time courses. As a means of distinguishing between the different effects, an important functional distinction has been raised between processes supporting explicit retrieval per se, and distinct post-retrieval processes operating upon retrieved information. This distinction is based on the notion of separate memory and

working-with-memory systems, which was first introduced in chapter 1 in the context of the review of behavioural studies of explicit and implicit memory.

In the penultimate section of this chapter presented below, a final means of investigating the relationship between the ERP old/new effects and explicit memory is introduced. The studies reviewed in the following section employed ERPs to assess whether or not indirect tasks engage both explicit and implicit memory.

3.3 ERPs and Explicit Retrieval: Indirect Tasks

The studies discussed above provide evidence associating old/new effects with recollection. Recollection, as discussed in Chapter 1, is perhaps best considered as the explicit retrieval of information from specific prior episodes. As also discussed in Chapter 1, explicit memory is not always contingent upon an intention to retrieve. Such 'involuntary' forms of explicit memory have been subject to much recent study because of the possibility that they may contaminate measures of priming on indirect tasks whose nominal purpose is to measure implicit retrieval (e.g. Schacter, Bowers and Booker, 1989).

A few ERP studies of indirect tasks have set out to investigate whether or not information is recollected involuntarily on indirect tasks, using ERPs as a covert and *on-line* measure of awareness during task performance (Paller and Kutas, 1992; Paller, Kutas and McIssac, 1995). These studies provide an interesting means to test the hypothesis that ERP old/new effects reflect explicit memory. First of all, the studies employ tasks which are, nominally at least, measures of implicit retrieval. If ERP correlates of explicit memory were observed on such tasks, this would provide good evidence for the contamination of such tasks by explicit memory. Second, according to the functional and neuroanatomical accounts of implicit and explicit retrieval reviewed in chapter 1, ERP correlates of memory retrieval should reflect different neural generator structures according to the type of retrieval (explicit vs.

implicit). ERP correlates of explicit and implicit retrieval should therefore differ qualitatively in terms of their scalp distribution (see chapter 2).

Finally, because the memory processes supporting explicit and implicit retrieval have been shown to differ functionally, it is to be expected that putative ERP correlates of each form of retrieval should also differ in terms of their sensitivity to different kinds of experimental manipulation. For example, ERP correlates of explicit memory would be predicted to show sensitivity to the depth of processing accorded to explicitly retrieved items at study. In the studies carried out to date, different indirect tasks have been employed. Paller and Kutas (1992) utilised data-driven indirect tests of tachistoscopic perceptual identification (PID). Paller, Kutas and McIssac (1995) employed the lexical decision task. A review of the findings of these studies is provided below.

In the ERP studies noted above, the functional independence of priming and explicit memory was tested by employing a depth of processing manipulation to alter the probability of explicit retrieval of items at test. In contrast, this manipulation should not affect processes supporting priming, as assessed by behavioural measures of performance on the tasks. In each study, ERPs evoked at test were compared as a function of study status (studied vs. unstudied) and also as a function of the nature of the study task (deep vs. shallow). Across studies, ERPs for deeply studied items were more positive-going than those to items accorded shallow study, and those to unstudied items. In addition, ERPS for shallowly studied items did not differ from those to unstudied items (Paller and Kutas, 1992; Paller, Kutas and McIssac, 1995). The critical feature of these three studies was that the behavioural measures of task performance were unaffected by the study manipulation of depth of processing, while ERP correlates of task performance were highly sensitive to the study manipulation.

By dissociating the effects of the depth of processing manipulation on two different measures of task performance, the above studies indicate that each measure reflects

functionally distinct processes. In line with the previous ERP studies of the direct recognition memory task, the ERP effects were interpreted as reflecting explicit memory for studied items, which was reduced or eliminated for items accorded only shallow study. Since the performance measures were not sensitive to depth of processing, it was argued that the explicit memory revealed by the ERP effects did not reflect any intention on the part of the subjects to deliberately retrieve studied items. This conclusion is based on the following argument. If subjects had deliberately tried to retrieve study items, then each task would have effectively become a recognition memory task, and performance on recognition memory tasks is highly sensitive to depth of processing (e.g. Paller, Kutas and McIssac, 1995). Since the performance measures were not in fact sensitive to depth of processing, the explicit memory reflected by the ERP measures was thus an *involuntary* consequence of the re-presentation of the studied items at test.

These findings fit very well with those reported by Richardson-Klavehn and colleagues (e.g. Richardson-Klavehn, Gardiner and Java, 1996; and see chapter 1), where an on-line behavioural measure of awareness was employed. This indicates that the ERP and behavioural on-line measures may possibly be reflecting similar processes. The advantage of the ERP measures is that they provide information on the time course and patterns of brain activity which are associated with this explicit retrieval. On the other hand, the interpretation of the ERP old/new effects can also be guided by the concurrent employment of behavioural measures. These show that explicit retrieval is involuntary. Thus, the processing reflected by the parietal old/new effect cannot in some way index processes related to intentional retrieval, since this effect occurs on tasks where explicit retrieval is involuntary. This conclusion does not hold for the right frontal effect, which has not been observed to date on an indirect task. It may therefore be that the frontal effect has more to do with some aspect of strategic processing, invoked by the particular demands of direct tasks, related to explicit retrieval, but this is by no means established.

3.3.1 ERPs and Indirect Tasks: Summary

The above studies employed ERPs as a covert, on-line measure of awareness during performance on indirect tasks. Across studies, old/new ERP effects were observed solely in conditions where deeply studied items were presented at test. Shallow study of items did not lead to an ERP old/new effect at test. In contrast, behavioural measures of task performance were unaffected by the study manipulation. The ERP effects were interpreted as reflecting the involuntary recollection of the prior occurrence of deeply studied items.

3.4 General Summary

The entire review given in the above sections has explored a variety of ways in which ERPs have been used to investigate explicit memory. As this research has developed, improvements to methodology were introduced. The critical improvements which I think have lead to genuine progress are 1) the use of better, and varied, operational definitions of recollection. 2) the use of recording epochs with >1s duration. 3) the employment of a large number of electrodes (from 13 upwards) to better characterise and distinguish the scalp distributions of ERP components. 4) taking into account the process impurity of memory tasks, which has lead to 5) the use of ERPs as a covert means of monitoring explicit memory on indirect tasks. 6) the employment of manipulations which selectively affect explicit memory, to distinguish between processes reflected by behavioural and ERP measures of performance.

These methodological points have allowed critical conclusions to be drawn about the ERP old/new effects. The reviews given above indicate primarily that ERPs are sensitive to neural activity associated with explicit forms of memory. Studies have not as yet provided good evidence for an ERP correlate of implicit retrieval. The above studies also show that there are multiple ERP correlates of processes

associated with explicit memory. The parietal effect in particular is the most robust finding, since it has been observed, without exception, across studies employing quite different paradigms (e.g. perceptual identification and associative recognition). Right frontal old/new effects are observed less widely, and their functional interpretation is correspondingly less clear at the moment.

3.5 The Present Studies

The results of six empirical studies are presented. These studies are organised along the following lines. In the first three exploratory studies (Chapters 5, 6 and 7), ERP correlates of performance on cued recall and stem completion are investigated. In these studies, encoding conditions are manipulated (using the depth of processing manipulation) while retrieval cues are held constant. These studies assess the effects on ERPs of the implicit and explicit retrieval of studied items cued by word-stems. The studies thus allow a comparision between any observed ERP correlates of retrieval and the old/new ERP effects previously observed on the direct and indirect tasks reviewed above. However, the major aim of these studies is to determine whether or not explicit retrieval, as reflected by ERPs, is a feature of performance on these two direct and indirect tasks. A more specific introduction to these studies is provided in Chapter 5. This introduction spells out in more detail the predictions regarding ERP correlates of implicit and explicit retrieval which can be made on the basis of what is known about the functional neuroanatomy of the processes on which retrieval depends.

Having established that ERPs do reflect explicit, and possibly implicit, retrieval on tests of cued recall and stem completion, experiments 4 and 5 (Chapters 8 and 9) set out to contrast the cued recall ERP effects with old/new effects observed on tests of recognition memory. The purpose of these two studies is to determine whether or not the ERP effects observed on each task reflect similar cognitive processes. The studies employ topographical analyses of the distribution of ERP effects from each

task to demonstrate whether or not this is the case. Once more, a specific introduction to these studies is provided in chapter 8.

In the final study presented in Chapter 10, ERP correlates of explicit retrieval on the cued recall task are investigated using an operational definition of recollection in terms of source memory. In this study, subjects were required to discriminate the temporal context of item presentation at study, following the successful retrieval of the item itself using word-stems as retrieval cues. This study further investigates the nature of the processes contributing to ERP effects on the cued recall tasks, and is introduced in more detail in Chapter 10.

4.0 General Methods

4.1 Introduction

Experimental procedures which are common to each experiment are given in this chapter. The method sections for individual experiments detail the procedures which are specific to each study. Each study has the following aspects in common. The selection criteria for subjects, the methods used to form a pool of experimental stimuli, stimulus presentation parameters and methods of ERP recording and analysis. Each aspect is dealt with in turn in the following sections.

4.2 Subjects

Experimental subjects were recruited from the undergraduate and post-graduate population of the University of St Andrews. All subjects were native English speakers, and had normal or corrected-to-normal vision. Subjects were between 18 and 35 years old.

4.3 Stimuli

The stimuli used in each experiment were drawn from the Francis and Kucera (1982) corpus. The primary criterion governing the choice of stimuli was that the first three letters (stem) of each item should be unique, and also begin at least 5 different English words. A pool of 500 target items was selected with these criteria. The stimuli used in experiments 1 and 2 are given in part A of the Appendix to the thesis. The stimuli used in experiments 3-6 are given in part B of the Appendix. The

procedures used to create item lists are detailed in the method section for each experiment.

In each experiment, stimuli were presented visually in upper case on a computer monitor (in white, on a black background). All stimuli were presented in central vision (individual method sections provide further details).

4.4 ERP Recording

EEG was recorded from tin electrodes fixed in an elasticated cap (Electro-cap Inc.) and positioned according to the conventions of the International 10-20 system (Jasper, 1958). The full electrode montage is depicted in figure 4.1. A subset of 13 of these 25 sites (termed hereafter the 'standard montage', and depicted in figure 4.2) was used in experiments 1, 2 and 3. These figures are placed at the end of this chapter. The full montage was used in experiments 4, 5 and 6, where topographical analyses (see below) were performed on the distribution of ERP effects. The method sections of individual studies specify the particular montage used. All EEG channels were recorded with reference to linked electrodes placed on each mastoid bone (method sections of individual experiments detail how references were used). An electro-oculogram (EOG) was also recorded bipolarly from each subject using electrodes placed above the supra-orbital ridge of the right eye and adjacent to the outer canthus of the left eye.

Prior to electrode placement, the skin underlying each electrode site was lightly abraded. Following electrode placement, colloidal conducting gel was injected into the well of each electrode. Each procedure acts to reduce the level of impedance between electrode pairs, thereby attenuating the induction of environmental electromagnetic artifact. Inter-electrode impedances below 5KW were deemed acceptable.

Each amplifier channel had a time constant of 5s, and the high pass filter setting was 35Hz (3db points). Sampling rate varied across experiments (see individual method sections for details), but in each study the recording epoch was composed of 256 sample points, digitised at 12 bit resolution. Prior to averaging, the DC offset of each channel was removed from the EEG and EOG by subtracting the mean amplitude of the pre-stimulus baseline period from the value for each of the remaining post-stimulus sample points.

The hard disk of an IBM PC compatible computer was used to store EEG data on-line. Analysis of EEG data was conducted off-line following each session. Certain criteria were imposed in the process of forming averaged ERP data so as to reduce the possibility of waveform contamination from extra-cerebral artifact. Individual trials were excluded from the averaging process if any of the following criteria were violated: 1) peak EOG activity which exceeded +/-122mv; 2) drift from baseline exceeding a criterion level (specified in the method sections of individual studies) at any electrode site. This was computed as the difference between the first and last data point of each waveform. 3) saturation of analogue to digital converters.

With the exception of one subject in the first reported experiment below (see chapter 5), a criterion of 16 artifact free trials per experimental condition per subject was used to ensure an acceptable signal-to-noise ratio in averaged ERPs. If a subject did not contribute sufficient trials in critical conditions they were excluded from the analyses of those conditions. All ERP analyses were performed on averaged data which had been smoothed using a 5-point binomial filter.

4.5 Analyses of ERP Data

4.5.1 Analyses of 'raw' ERP Data

Analysis of variance (ANOVA) was used to contrast ERPs from different experimental conditions. All ANOVAs were conducted upon mean amplitude measures of selected latency regions computed relative to the mean amplitude of the pre-stimulus baseline period (the exact duration of the baseline period varied slightly across experiments, see individual method sections for details). In each study, ANOVAs were initially conducted upon ERPs from the standard montage of 13 electrode sites. ERPs from sites not included in the standard montage were, however, used in the topographical analyses of ERP data reported in experiments 4, 5 and 6 (chapters 8, 9 and 10) (for details see section below).

A core set of ANOVAs were performed in each experiment. These took the form of separate analyses of data from the midline and lateral electrode sites of the standard montage. Analyses of data from the midline sites used the factors of condition and electrode site. Analyses of data from the lateral sites included the additional factor of hemisphere. Significant effects which did not involve the factor of condition are not reported. All ANOVAs of ERP and behavioural data incorporated the Geisser-Greenhouse correction for heterogeneity of covariance (Keselman and Rogan, 1980). All post-hoc tests for ERP and behavioural data analyses used the Newman-Keuls or Tukey HSD methods, with a significance level of $p < 0.05$.

4.5.2 Topographical Analyses of ERP Effects

Analysis of variance was also used to contrast the distribution of ERP effects across the scalp in different experimental conditions. These topographical analyses were performed upon 'rescaled' ERP data. Rescaling of the raw ERP data is necessary since analysis of variance assumes that changes in variance represent additive effects of underlying factors. For ERP data, this assumption is not tenable since changes in the strength of a generator have a multiplicative effect on recordings taken from scalp electrodes (McCarthy and Wood, 1985). This means that ANOVA of raw ERP data can give rise to interactions involving the factor of site which result from a quantitative change in the activity of a single generator. Accordingly, if one wishes

to determine whether there exists a qualitative difference in generators contributing to different ERP effects, then the ERP data must be corrected to remove the confounding effects of across condition and/or across latency region differences in amplitude on scalp distribution.

The method chosen to rescale the raw ERP data was proposed by McCarthy and Wood (1985). This method involves computing the size of the ERP effect in each condition at each electrode site relative to the size of the effect at all other sites. This method thus maintains the pattern of relative differences in effect size across the scalp while removing amplitude differences.

4.5.3 Onset Latency Analyses

Where reported, the onset latency of differences between ERPs was determined using a series of t-tests conducted upon subtraction waveforms formed by subtracting, at each site, ERPs in one condition from those in another condition. The t-tests assessed whether the value of each resulting individual data point was significantly greater than zero ($p < 0.05$). Onset latency was defined as the point from which 15 or more consecutive data points were significantly greater than zero. This criterion, which is standardly used in the St Andrews laboratory, reduces the probability of type-I error; (i.e. of accepting as genuine an effect manifest as a shorter series of significant outcomes).

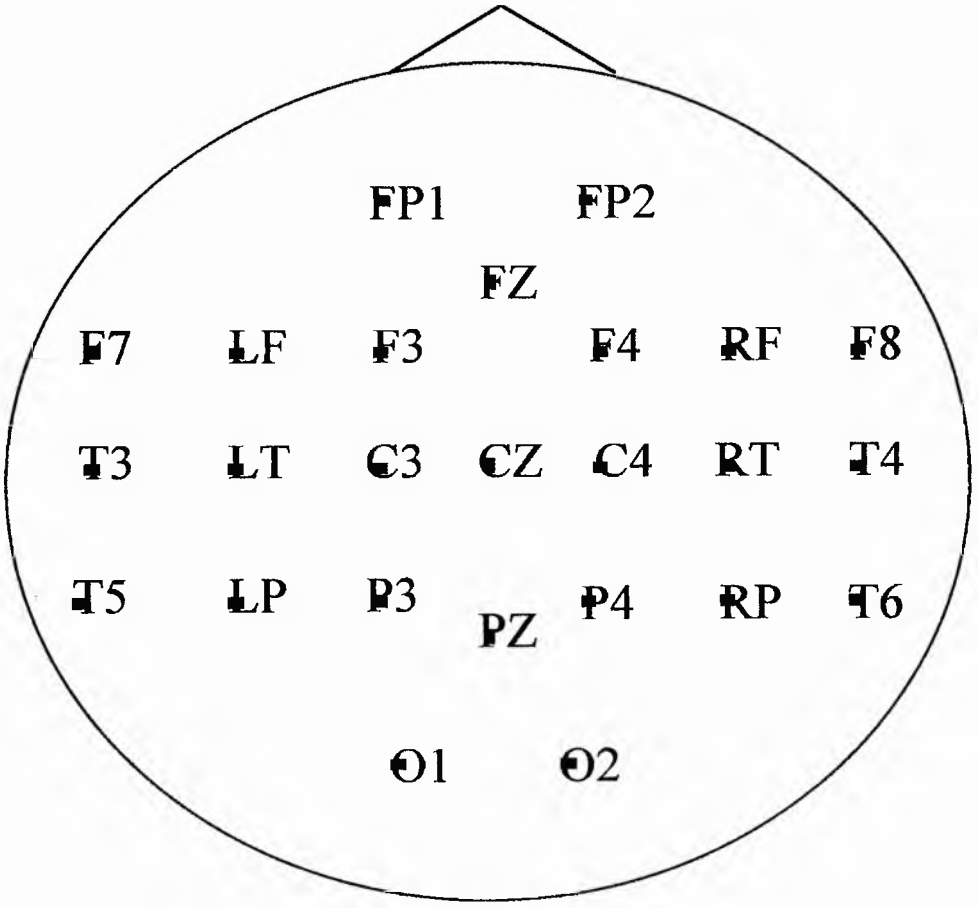


Figure 4.1 Locations on the scalp of the 'full electrode montage' consisting of 25 electrodes, used in experiments 4, 5, and 6. Electrodes are positioned at Fp1, Fp2, Fz, Cz, Pz and at the following homologous left and right hemisphere sites: F7/F8, LF/RF (frontal, 75% of the distance from Fz to F7/F8), F3/F4, T3/T4, LT/RT (anterior temporal, 75% of the distance from Cz to T3/T4), C3/C4, T5/T6, LP/RP (lateral parietal, 75% of the distance from Pz to T5/T6), P3/P4, 01 and 02.

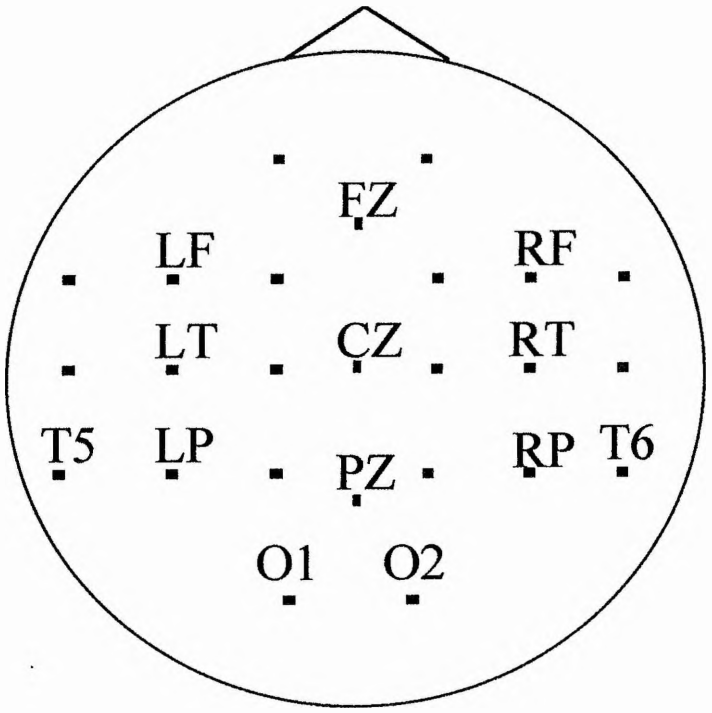


Figure 4.2 Locations on the scalp of the 'standard electrode montage' used in all six studies. These 13 sites are a subset of the 25 sites of the full electrode montage. Fz, Cz and Pz signify midline frontal, central and parietal sites. LF, RF, LT, RT, LP, RP, T5, T6, O1 and O2 signify left and right frontal, anterior temporal, parietal, posterior temporal and occipital sites, respectively. Analyses of ERPs in all six studies were performed primarily on the data from these 13 sites, thus allowing across experiments comparison of the ERP findings.

5.0 An Event-Related Potential Study of Word-Stem Cued Recall

5.1 General Introduction (Experiments 1, 2 and 3)

The three studies presented in this part of the thesis attempt to identify and contrast ERP correlates of explicit and implicit retrieval. In experiment 1, ERP correlates of retrieval are investigated using a cued recall task. In experiments 2 and 3, ERP correlates of retrieval are investigated using a stem completion task (see Chapters 6 and 7). Each study employs a depth of processing manipulation to gain experimental control over explicit retrieval at test on both the cued recall and stem completion tasks. Importantly, this study manipulation allows a means of affecting both explicit memory (recollection), and implicit memory dependent upon conceptual forms of priming. In contrast, the study manipulation should not affect the probability of priming based upon facilitated perceptual processing.

To reiterate a major point from chapter 1, it is likely that cued recall and stem completion are not, respectively, pure measures of explicit and implicit memory. The present studies thus had to take account of this important notion, and in addition attempted to provide evidence supportive of it. In order to achieve this aim, a modified version of the cued recall instructions was developed. This modification allowed the formation of ERPs for conditions where retrieval of studied items is, and is not, accompanied by explicit memory (see the introduction section below for more details on this). In contrast, the stem completion instructions are typical of the previous studies discussed in chapter 1.

Certain 'basic' predictions regarding ERP correlates of explicit and implicit retrieval may be given here. These predictions apply to all three studies, and follow from the presumed functional and neuroanatomical independence of processes associated with

implicit and explicit memory (see Chapter 1). First, ERP correlates of processes associated with explicit memory and implicit conceptually-based priming, should both be modulated as a function of the depth of processing accorded to items at study. Second, ERP correlates of explicit and implicit memory should be qualitatively different (in terms of scalp distribution). Third, ERP correlates of processes associated with implicit perceptually-based priming, should be insensitive to study depth of processing, and in addition should be qualitatively different from any ERP correlates of explicit memory and conceptual priming.

5.2 Introduction (experiment 1)

In the present study, ERPs were recorded during the test phase of a cued recall task in which 50% of word stems could be completed by a previously studied word, while the remainder could not. The task requirement was to use each stem to attempt to recall a studied word or, if recall failed, to respond with the first completion to come to mind. In a departure from most previous studies of cued recall, subjects were required to judge overtly whether each completion corresponded to a studied or an unstudied word. The modification to the cued recall instructions is similar to that introduced by Richardson-Klavehn and colleagues (Java, 1994; Richardson-Klavehn, Gardiner and Java, 1994; Richardson-Klavehn and Gardiner, 1995) in their studies of stem completion and cued recall. The present task modification permits correct completions accompanied or unaccompanied by explicit memory for the study episode to be separately identified, in an on-line manner. Thus, a pure measure of explicit and implicit retrieval, so defined, may be obtained. Thus, the present study permits a contrast between ERPs which are evoked by word stems that cue either explicit or implicit retrieval of a studied item.

5.3 Method

5.3.1 Subjects

Subjects were 26 young adults, each paid £3.50 per hour. Of these 26 subjects, 2 failed to complete the experiment, while the data from a further 5 were discarded due to movement-related artifact present in their EEG, which resulted in too few artifact-free trials with which to form ERPs in critical conditions. Of the remaining 19 subjects, nine were female and 17 were right handed. Their mean age was 20 years (range 18-24). All were native English speakers, and had normal or corrected-to-normal vision.

5.3.2 Stimuli

The experimental stimuli were drawn from the 500 item experimental word pool. The pool was partitioned at random into two sets of 200 critical words, under the constraint that word length should be between 4 and 9 letters. Each set of 200 critical words was used to create four study lists. Each study list contained 200 critical items, with 5 buffer items at the beginning and the end of each list. Half of the words in each list were studied in one of the two encoding tasks, and the remainder were studied in the other task. The order of presentation of words and the task order were counterbalanced across lists. Every study list had a corresponding test list, consisting of 405 word stems. The first five stems were buffers and belonged to unstudied items. Of the remaining 400 stems, 200 stems belonged to the studied items and the remaining 200 stems belonged to the 200 critical words not shown at study.

Stimuli subtended maximum horizontal and vertical visual angles of 1.5 deg and 0.4 deg, respectively. Word stems subtended maximum horizontal and vertical visual angles of 0.5 deg and 0.4 deg, respectively. On each study trial, subjects were initially presented with a fixation character at the centre of the screen (either a 'X' or a '#') which indicated the task for each trial. The fixation character was positioned approximately where the third letter of each word was to be displayed. Each word

was displayed for 300ms, following which the screen was blanked for 2s before the fixation character reappeared.

Each test phase trial began with the display of an exclamation mark, which was removed after 2s, and followed immediately by a fixation asterisk positioned approximately where the middle character of each stem was to be displayed. The asterisk remained on screen for 1s. The screen was then blanked for 120ms, followed by presentation of a stem for 300ms. The screen was then blanked for 2.7s, at which point a question mark was displayed in the same position as the fixation asterisk, indicating to the subject that a response was now to be given. Following a 3s period for responding, the exclamation mark was redisplayed, signalling the beginning of the next trial.

5.3.3 Procedure

Following application of the recording cap, subjects were seated in front of a desk on which response buttons and the stimulus presentation monitor were situated. Two study tasks were employed: the 'semantic' task required subjects to judge whether or not a word's meaning was pleasant; the 'non-semantic' task required subjects to judge if the vowels in a word were in alphabetic order. Stimulus presentation was self-paced, and was initiated by a button press which could be made any time after the display of the fixation character. This character also indicated the task for that trial ('X' = non-semantic task, '#' = semantic task). Instructions were to respond by pressing one of two buttons (indicating either a pleasant / unpleasant, or alphabetic / nonalphabetic, judgement) within the 2.3 second period following word onset, after which the fixation character for the next trial was displayed. On completion of the study phase subjects were given a five minute rest.

Subjects were then informed that of the stems they were about to see, half could be completed by studied words, and that their task was to use each stem to aid recall of one of these words. They were further instructed that if they were unable to recall a

study word, they should give the first suitable word which came to mind as a completion for the stem. Subjects were given 3s to think of a completion from the onset of each stem, but were instructed to withhold their response until the 3s period had elapsed, and a question mark character had been displayed. In addition to responding with a word that completed the stem on each trial, subjects were further instructed to indicate (by saying 'old' or 'new') whether the word had been studied. To minimise movement-related EEG artifact, subjects were asked to remain as relaxed and as still as possible during each trial. They were also instructed to refrain from blinking during the period beginning with the display of the fixation asterisk and ending with the display of the question mark (approximately 4s). A one minute break was given after every 100 stems. On completion of the test phase subjects were debriefed.

5.3.4 ERP Recording

EEG was recorded from the 13 electrodes of the standard montage (see chapter 4, figure 4.2). The EEG from these electrodes was recorded with respect to a linked mastoid reference. All channels were amplified with a bandpass of 0.03 to 30Hz (3dB points), and were sampled on-line at a rate of 6ms per point. The total recording epoch was 1536ms, beginning 102ms prior to stimulus onset. The total duration of recorded post-stimulus EEG was therefore 1434ms.

The drift-from-baseline EEG criterion was +/- 80μv in the present study. All trials where baseline drift exceeded this criterion were excluded from the averaging process. ERPs were formed from each subject for conditions where there were at least 16 artefact-free trials available, with the exception of one subject, who contributed only 15 trials to ERPs evoked by stems attracting the implicit retrieval of studied items (see results).

5.4 Results

As mentioned in the methods, not all subjects contributed sufficient trials to form ERPs for all critical conditions. Because of this, the ERP analyses reported below were conducted on three data sets, from 16, 13 and 11 subjects respectively. All of the 13 subjects, and 8 of the 11 subjects, were included within the 16 subject group.

5.4.1 Behavioural Data

The following analyses were conducted on the data of the nineteen subjects whose ERPs were employed in one or more of the analyses described in the next section (the identical pattern of results was observed in the analysis of the data from all 24 of the subjects who completed the experiment). The data are summarised in table 5.1. Baseline completion was estimated for each subject by an analysis of the responses made to the stems belonging to the set of 200 critical items that had not been presented at study. The baseline rate is an estimate of the probability that the stem of a critical word will be completed with that word in the absence of prior study. This estimate can thus be used to determine whether completion rates for studied words were significantly higher than chance.

A one-way ANOVA of the completion rates for semantically studied, non-semantically studied and unstudied baseline items gave rise to a significant effect [$F(1.7, 30.5) = 81.9$; $p < 0.001$]. Post-hoc analysis revealed that completion rates for semantically and non-semantically studied items were greater than the baseline completion rate. In addition, significantly more completions were made with semantically than non-semantically studied items. Recognition scores for studied words were corrected for guessing by subtracting the false alarm rate, defined as the proportion of completions to stems belonging to unstudied words that were falsely judged to be old. The corrected recognition score for semantically studied items was significantly larger than that for non-semantically studied items ($t(18) = 7.39$; $p <$

0.001), and both scores were significantly greater than chance ($t(18) = 9.26$; $p < 0.001$], and $t(18) = 4.96$; $p < 0.001$, respectively).

5.4.2 Event-Related Potentials

ERPs were initially subjected to exploratory analysis by ANOVA of mean amplitudes of consecutive 100ms latency regions. From 500ms post-stimulus, these ANOVAs gave rise to a consistent pattern of highly significant effects at midline and lateral sites. From 1000ms post-stimulus, the ANOVAs revealed additional differences between the ERPs evoked by stems attracting the explicit retrieval of studied items as a function of study condition (semantic vs non-semantic). On the basis of these analyses, two broad latency regions, 500-1000ms and 1000-1434ms were selected for futher detailed analysis, as described below. Estimates of the onset latency of differences between ERPs were determined by the procedure given in the general methods section.

The results of four critical ERP comparisons are presented. In the first comparison, ERPs evoked by stems of studied words attracting correct completions are contrasted with those evoked by stems completed with unstudied baseline items (see figure 5.1). The ERPs were obtained from 16 subjects, and the averages were generated without regard to recognition decision and therefore form of retrieval (explicit or implicit). The purpose of this comparison was to determine whether ERPs were sensitive to the study status of completions, as a prelude to the further comparisons presented below.

5.4.2.1 ERPS as a Function of Study Status

The mean number of trials in the ERPs evoked by stems completed with semantically and non-semantically studied items were 38 (range 23-50) and 31 (18-41), respectively. The mean number of trials in the ERPs evoked by stems completed with unstudied baseline items was 30 (22-47). Inspection of the waveforms in figure 5.1 suggests that only ERPs evoked by stems completed with semantically studied

words differ from those evoked by stems completed with unstudied baseline items. This difference takes the form of an enhanced positivity, maximal at anterior electrode sites, which onsets around 350ms, and continues until the end of the recording epoch.

ANOVAs of the data from midline sites gave rise to significant condition by site interactions for both the 500-1000ms and 1000-1434ms latency regions ([$F(2.4,35.4) = 4.26$; $p < 0.025$] and [$F(2.6,39.1) = 3.49$; $p < 0.05$], respectively). Post-hoc analyses revealed an identical pattern of effects for the two latency regions: at Fz and Cz, ERPs evoked by stems completed with semantically studied items were more positive than those for the other two conditions, which did not differ from each other. ANOVA of the data from the lateral sites during the 500-1000ms latency region also gave rise to a significant condition by site interaction [$F(2.5, 37.4) = 4.33$; $p < 0.025$]. Post-hoc analyses revealed that at frontal and temporal sites ERPs evoked by stems completed with semantically studied items were more positive than ERPs for the other two conditions, which did not differ from one another.

ANOVA of the data for the lateral sites during the 1000-1434ms latency region gave rise to a significant main effect of condition [$F(1.8, 26.6) = 9.16$; $p < 0.001$], and to a condition by site interaction that approached significance [$F(2.3, 34.6) = 3.0$; $p < 0.06$]. The condition effect was due to positivity in the ERPs evoked by stems completed with semantically studied items relative to ERPs for the other two conditions, which did not differ from one another. The condition by site interaction reflects the fact that the effects are largest at frontal and anterior temporal electrode sites.

5.4.2.2 ERPS to False Alarms

A second comparison was performed upon data from the same 16 subjects, and contrasted three classes of ERP: i) those evoked by stems of semantically studied words that were both correctly completed and recognised (hereafter, semantic hits),

ii) ERPs to unstudied word stems for which completions were correctly judged to be new (correct rejections) and iii) ERPs to unstudied word stems when the completion was incorrectly judged to be old (false alarms) (figure 5.2). This comparison determined whether ERPs evoked by stems associated with false recognition judgements more closely resemble ERPs evoked by hits or correct rejections.

The mean number of trials in the ERPs shown in figure 5.2 were 34 (22-49), 121 (74-175) and 45 (16-80), for semantic hits, correct rejections and false alarms, respectively. The figure shows that ERPs evoked by correct rejections and false alarms do not appear to differ. However, the ERPs evoked by semantic hits exhibit an enhanced positivity (essentially identical to that shown in figure 5.1), relative to ERPs for the other two conditions.

ANOVAs of the 500-1000ms latency region data gave rise to significant condition by site interactions for both midline and lateral sites ([$F(1.9, 29.0) = 5.76$; $p < 0.01$] and [$F(2.0, 30.2) = 4.28$; $p < 0.05$] respectively). Post-hoc tests revealed that at Fz and Cz the ERPs to hits were more positive than the ERPs evoked by either of the remaining two classes of item, which did not differ from one another. Post-hoc analysis following up the condition by site interaction at lateral sites revealed no significant differences. None the less, the pattern of the data indicate a trend for the condition effects to be largest at the frontal and anterior temporal electrode sites.

The ANOVA of data from the midline sites during the 1000-1434ms latency region gave rise to a condition by site interaction [$F(1.6, 24.6) = 4.3$; $p < 0.05$]. Post-hoc tests revealed that at Fz and Cz the ERPs evoked by hits are more positive than the ERPs from the other two conditions, which did not differ from one another. ANOVA of data from the lateral sites gave rise to a main effect of condition [$F(1.3, 20.1) = 7.96$; $p < 0.01$], and to a condition by site interaction which approached significance [$F(2.2, 32.6) = 2.64$; $p < 0.09$]. Post-hoc tests revealed that the main effect was due to enhanced positivity in the ERPs to hits relative to the other two classes of ERP, which again did not differ from each other.

5.4.2.3 Effects of Study Task

Of the two remaining comparisons, the first was conducted on data from 13 of the 16 subjects, and involved contrasting ERPs evoked by semantic hits, non-semantic hits, and correct rejections (figure 5.3). Thus, this comparison contrasts ERPs associated with explicit memory as a function of depth of processing at study.

The mean number of trials in ERPs shown in figure 5.3 were 35 (22-49), 21 (16-31) and 117 (74-175), for semantic hits, non-semantic hits and correct rejections, respectively. Table 5.2 shows mean amplitude values of the 500-1000ms and 1000-1434ms latency regions of these ERPs. Inspection of figure 5.3 reveals that ERPs evoked by semantic and non-semantic hits both show enhanced positivities, relative to ERPs evoked by correct rejections, which are again maximal at anterior electrode sites. From 1000ms onwards, the ERPs evoked by semantic hits are the more positive at Fz and Cz. This difference between the two study conditions is smaller at lateral sites.

ANOVAs of data from the midline and lateral sites during the 500-1000ms latency region each gave rise to main effects of condition ([$F(1.8, 21.3) = 6.57$; $p < 0.01$] and [$F(1.6, 9.4) = 5.16$; $p < 0.025$], respectively). Post-hoc analyses of these main effects gave identical results: ERPs evoked by semantic and non-semantic hits did not differ from one another, but both were more positive than those evoked by correct rejections. ANOVA of the data from the lateral sites also gave rise to a significant condition by site interaction [$F(2.7, 31.8) = 3.1$; $p < 0.05$]. Inspection of the waveforms shown in figure 5.3 indicates that the interaction arose because the differences between the waveforms are largest at frontal and anterior temporal electrodes. However, post-hoc analyses failed to confirm this impression.

ANOVA of the data from the midline sites from the 1000-1434ms latency region gave rise to a significant main effect of condition [$F(1.7, 20.6) = 5.97$; $p < 0.025$].

Post-hoc analyses revealed that the ERPs to semantic hits were more positive than those to correct rejections. No other differences were significant. ANOVA of data from the lateral sites also gave rise to a significant main effect of condition [$F(1.5, 18.4) = 6.77$; $p = 0.01$]. Post-hoc analyses showed that for these sites, the ERPs evoked by semantic and non-semantic hits did not differ, but both were more positive than those to correct rejections.

5.4.2.4 Explicit vs. Implicit Retrieval of Studied Items

In the final comparison, data from 11 subjects were used to contrast ERPs evoked by hits, by stems that were correctly completed with an unrecognised study word (misses), and by correct rejections (see figure 5.4). This comparison permits a contrast of the effects on ERPs of retrieval accompanied (hits) or unaccompanied (misses) by explicit memory. Because of the small number of available trials, it was not possible to form separate ERPs as a function of study task, and the ERPs to hits and misses were therefore collapsed across this variable. The mean number of trials in ERPs shown in figure 5.4 were 50 (36-61), 24 (15-38) and 135 (80-176), for hits, misses and correct rejections, respectively. Figure 5.4 shows the by now familiar pattern of an anteriorly distributed positive shift in the ERPs evoked by hits, relative to those to correct rejections. This shift appears to be absent in the ERPs evoked by misses.

ANOVAs of data from the midline sites during the 500-1000ms and 1000-1434ms latency regions each gave rise to significant condition by site interactions ([$F(2.5, 25.3) = 6.09$; $p < 0.005$] and [$F(2.7, 26.8) = 4.39$; $p < 0.025$], respectively). Post-hoc analyses of these interactions gave identical results: at Fz, ERPs evoked by hits were more positive than ERPs for the other two conditions, which did not differ from one another. ANOVAs for lateral sites gave rise to no significant effects in either latency region although, as can be seen in figure 5.4, the differences between the lateral waveforms are, as on the midline, anteriorly distributed.

5.4.2.5 Onset Latency Analyses

To maximise the signal-to-noise ratio for this analysis, ERPs to semantic and non-semantic hits were collapsed to form a single set of waveforms, which were contrasted with the ERPs evoked by correct rejections. Point-by-point t-tests indicated that the enhanced positivity associated with hits first onset at the left anterior temporal site at 276 msec post-stimulus. The onset latency of the effect on the midline (Fz and Cz sites) was 348ms.

5.4.3 Summary of Results

A single memory-related ERP effect was observed. It took the form of a symmetrical, anteriorly distributed positive shift in ERPs elicited by stems attracting explicit retrieval (hits), relative to ERPs elicited by stems attracting implicit retrieval (misses) or stems completed with unstudied items (correct rejections and false alarms). The effect differed little according to whether items were subjected to semantic or non-semantic study.

5.5 Discussion

As expected, the depth of processing manipulation had a significant effect upon cued recall performance, with higher levels of correct completion for semantically than non-semantically studied items. Depth of processing had an even stronger effect on subsequent recognition judgements: stems completed with semantically studied items were much more likely to be correctly judged old than were those completed with words from the non-semantic task. The difference in recognition rates as a function of depth of processing is consistent with the proposal that cued recall is an impure measure of explicit memory (e.g. Jacoby, Toth and Yonelinas, 1993); if correct completion is always associated with explicit memory, no disparity between the contingent recognition rates would have occurred. Instead, the data suggest that one

effect of depth of processing manipulations on cued recall is to alter the proportion of correct completions associated with explicit memory (see also Java, 1994).

The sole memory-related ERP effect observed in this study was a sustained positive shift in ERPs evoked by hits (explicitly retrieved items), relative to those evoked by correct rejections. This difference, which was maximal over anterior regions of the scalp, onset around 300-350 ms post-stimulus and continued until the end of the recording epoch. The effect was not merely a consequence of making an 'old' recognition decision, since it was absent in the ERPs evoked by false alarms. Depth of processing at study did not affect either the onset latency or the scalp distribution of the effect, although it was somewhat smaller in the ERPs evoked by non-semantic hits, albeit only at midline electrode sites and late on in the recording epoch. Importantly, the effect is unlikely to be a consequence of the fact that the cued recall task employed in the present study was modified by the inclusion of a subsequent recognition decision; in a brief report, Haist and Kutas (1994) describe a seemingly identical ERP effect obtained in a standard cued recall task.

5.5.1 Explicit Retrieval

On the assumption that a subsequent recognition judgement can be used to identify stem completions associated with explicit memory, the ERP effect described above would appear to reflect the engagement of processes associated with explicit memory for study items. This conclusion follows from the finding (figure 5.4) that the effect is apparently absent when evoked by misses (implicit retrieval, stems correctly completed but unrecognised). The conclusion is further supported by the finding (figure 5.1) that the effect varies in magnitude according to the proportion of trials associated with positive recognition judgments (89% for the semantically studied items vs 55% for non-semantically studied).

The present findings do not however offer a clear guide as to the nature of the relationship between this ERP effect and the processes underlying explicit memory.

It is not possible, for example, to distinguish between the alternative possibilities that the effect is a direct reflection of neural processes supporting some aspect of memory retrieval, and that it reflects processes that are contingent upon retrieval. Nonetheless, the data do permit a strong conclusion to be drawn about the time-course of the processing of word-stem cues. It takes no more than about 300 msec for such a cue to engage differential processing predictive of the nature of a subsequent memory judgement. Such a short period of time is arguably more consistent with the first of the two alternatives discussed above, as it seems unlikely that retrieval could be completed within an interval that is probably not much longer than that required merely to have identified the retrieval cue.

One of the aims of the present experiment was to determine whether ERPs recorded at test were sensitive to the nature of the processing accorded study items. At first glance (figure 5.1), the answer to this question would appear to be affirmative. As is evident from the figure, only the ERPs evoked by stems that were completed correctly with semantically studied items differed from those to baseline stems. This pattern of effects is exactly analogous to those reported by Paller and Kutas (1992) and Paller, Kutas and McIssac (1995) in their studies of ERPs and indirect tasks. As noted in chapter 3, these researchers found positive-going ERP modulations at test only for items which had been deeply studied, as is observed in the present study. These findings led Paller and colleagues to conclude that the positive-going ERP modulation was a correlate of explicit retrieval, which occurred involuntarily in their studies, and which was sensitive to the depth of processing manipulation. The present ERP findings also suggest that explicit retrieval is affected by the depth of processing manipulation, such that items studied with the nonsemantic task are recollected significantly less often than semantically studied items. This is consistent with the behavioural data, discussed above.

As is clear from subsequent analyses, however, the findings take on a very different character when ERPs evoked by recognised completions (hits) only are compared (figure 5.2). Differences between the two study tasks are now confined only to late

regions of the recording epoch, and to midline electrode sites. Thus, there is rather little evidence that ERPs evoked by stems associated with explicit memory retrieval differ as a function of encoding task, suggesting that the retrieval (or other) processes reflected by these ERP effects are largely indifferent to the conditions under which the retrieved information was encoded. This conclusion is of course qualified by the finding, mentioned above, of some evidence of a difference between hit ERPs as a function of study task.

In any case, it appears that neural activity associated with explicit retrieval only differed quantitatively as a function of depth of processing, with the effect for semantically studied items being more sustained in amplitude and duration, particularly at midline sites. Further work is required to confirm the reliability of this effect, and its significance. It should also be noted here that the neural processing associated with explicit retrieval, as a function of depth of processing, may have differed to a much greater extent than is revealed by the ERPs. Not all of the neural activity associated with retrieval need, after all, give rise to a detectable ERP signature.

5.5.2 Implicit Retrieval

There was no evidence in the present study to suggest that ERPs were modulated by processes associated with implicit memory. Such evidence could have come from two sources: most importantly, from the comparison between misses and correct rejections (figure 5.4), and secondarily, from that between completions with semantically and non-semantically studied items unconditionalized on recognition performance (figure 5.1). On the assumption that a significant proportion of misses were associated with implicit retrieval of the study item, ERP effects reflecting implicit memory should have differentiated these ERPs from those to correct rejections, but no such effects were evident. Evidence for implicit memory effects could also have taken the form of differences from the unstudied baseline ERPs that were equal in size for completions from the two study conditions, or which were

larger for the nonsemantic condition (the condition containing the higher number of recognition failures). But no such differences were found. These negative findings therefore suggest that ERPs are less sensitive to processes underlying implicit than explicit memory, on this task.

5.6 Summary and Conclusions

The present study suggests that ERPs dissociate cued recall responses according to whether they are accompanied or unaccompanied by explicit memory. The findings therefore suggest that ERPs may play a useful role in identifying the circumstances in which other, similar tasks (such as word-stem completion) engage explicit memory. The behavioural data suggested that a proportion of studied items were retrieved implicitly. However, there was no evidence for an ERP effect which could be linked to priming.

The relationship between the present ERP effect and those observed in previous studies of recognition memory is taken up in the general discussion section which concludes this part of the thesis (see chapter 7). Suffice it to say that the topography of the cued recall ERP effect bears little resemblance to that of the ERP old/new effects observed for recognition memory (see chapter 3).

The present findings do not conclusively show that ERPs are insensitive to implicit memory; the negative findings in the present study might reflect a lack of power (emanating from small subject samples and relatively poor signal-to-noise ratios in the critical ERPs), and the unknown proportion of guesses contributing to stem completion with unrecognised studied items. In the following study, ERP correlates of performance on the stem completion task are examined. The following study thus provides a more direct means of addressing whether ERPs are sensitive to processing which supports the implicit retrieval of studied items.

Table 5.1 Behavioural data for experiment 1. Column 1: percent correct completion for stems belonging to studied items (collapsed across recognition decision), and percent baseline completion for unstudied items; column 2: percent recognition of correct completions; column 3: percent false recognition of completions of stems belonging to studied and unstudied items; column 4: conditional probability of correct recognition for correctly completed stems. SDs are shown in brackets.

	Completion Rate (%)	Recognition Rate (%)	False Alarm Rate (%)	Conditional Probability of Recognition
STUDIED				
semantic	42.3 (7.9)	37.9 (8.6)	13.2 (9.8)	0.89 (0.08)
non-semantic	35.3 (8.8)	19.6 (8.5)	13.1 (8.0)	0.55 (0.19)
UNSTUDIED	17.0 (3.2)	--	11.25 (6.7)	--

Table 5.2 Mean amplitude of the 500-1000ms and 1000-1434ms latency regions of ERPs evoked by hits and correct rejections.

	Fz	Cz	Pz	LF	LT	LP	T5	O1	RF	RT	RP	T6	O2
500-1000													
Semantic Hit	2.7	4.9	2.4	-0.1	3.6	0.8	-1.3	-1.6	2.2	3.6	0.1	-1.4	-1.5
Non-semantic Hit	2.2	4.3	1.8	-0.7	3.4	0.6	-1.2	-1.8	2.6	3.0	-0.7	-2.0	-1.8
Correct Rejection	-1.2	1.8	0.4	-3.0	0.8	-1.3	-2.4	-2.4	-0.1	1.5	-1.7	-2.2	-2.0
1000-1434													
Semantic Hit	7.1	5.8	1.5	2.8	4.6	1.3	-0.8	-0.5	6.5	5.5	2.2	0.6	-0.6
Non-semantic Hit	4.9	4.0	0.3	0.8	3.3	0.4	-1.0	-1.2	6.1	4.2	0.7	-0.4	-1.3
Correct Rejection	2.4	2.2	-0.7	-1.3	1.2	-1.6	-2.2	-1.9	3.3	2.7	-0.5	-1.0	-1.4

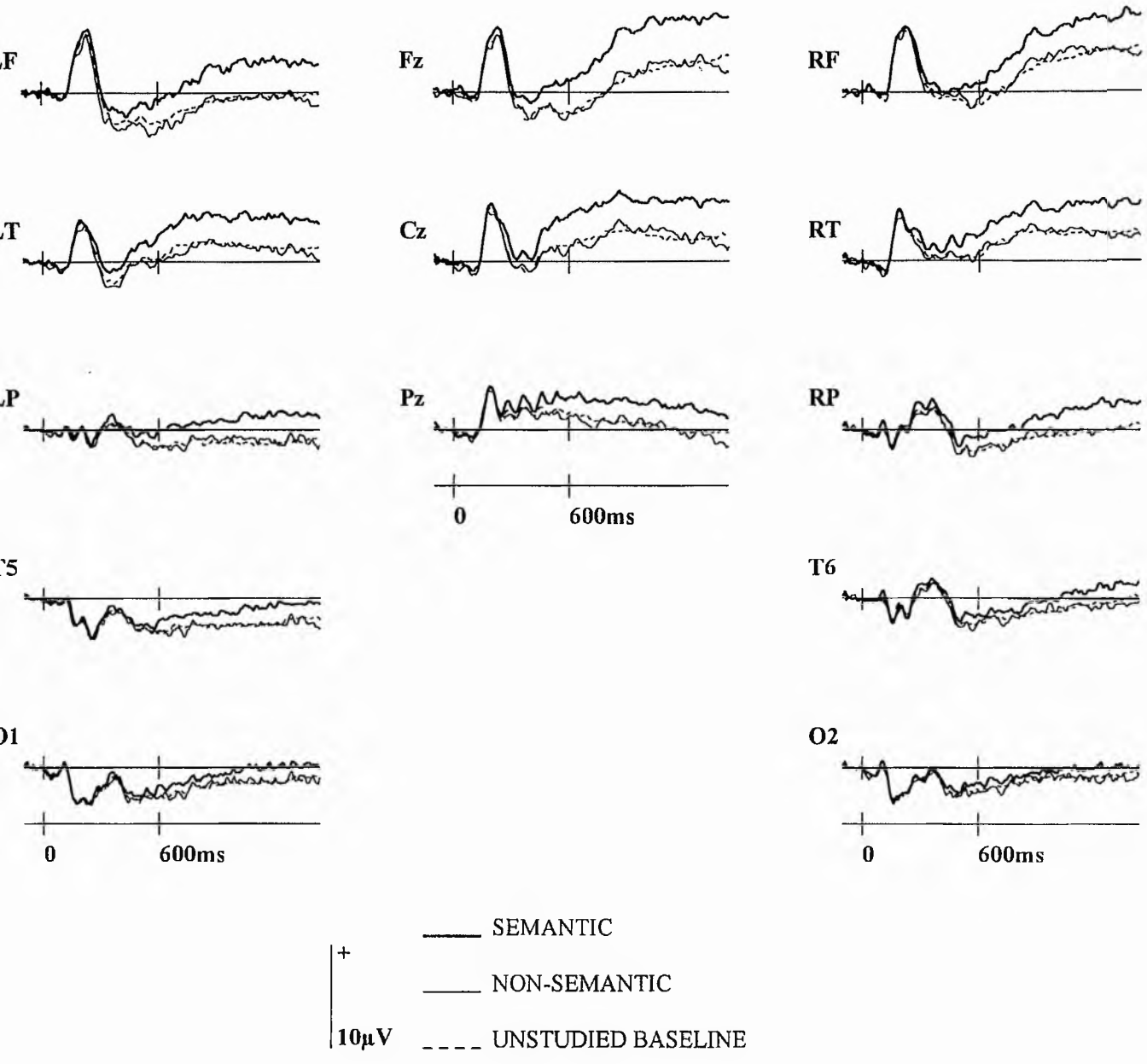


Figure 5.1 Grand average ERPs evoked by stems completed with semantically and non-semantically studied items, and ERPs evoked by stems completed with unstudied baseline items. All ERPs were formed by collapsing across recognition decisions. See General Methods chapter for description of site labels.

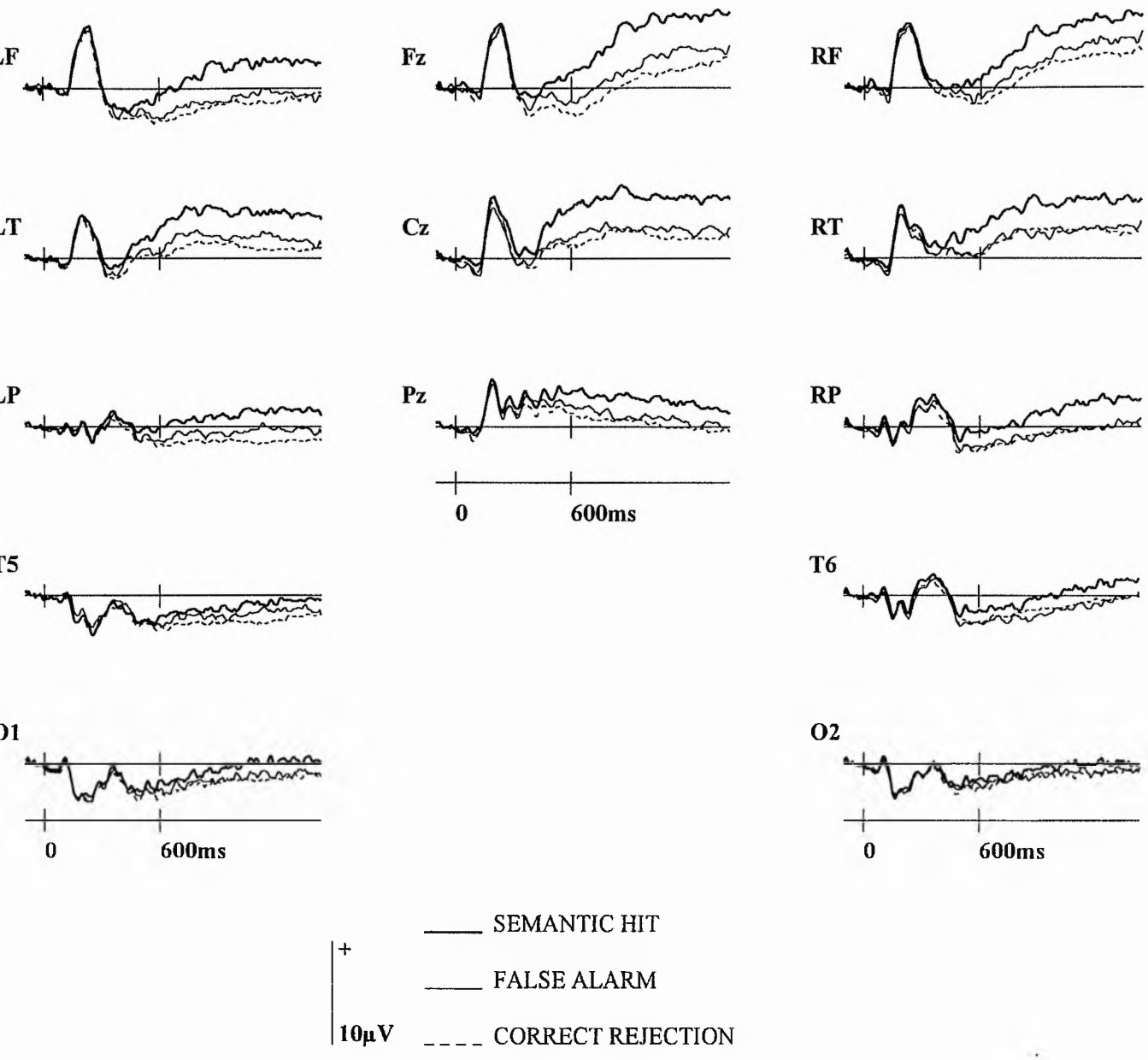


Figure 5.2 Grand average ERPs evoked by semantic hits, correct rejections and false alarms. Electrode sites as for figure 5.1.

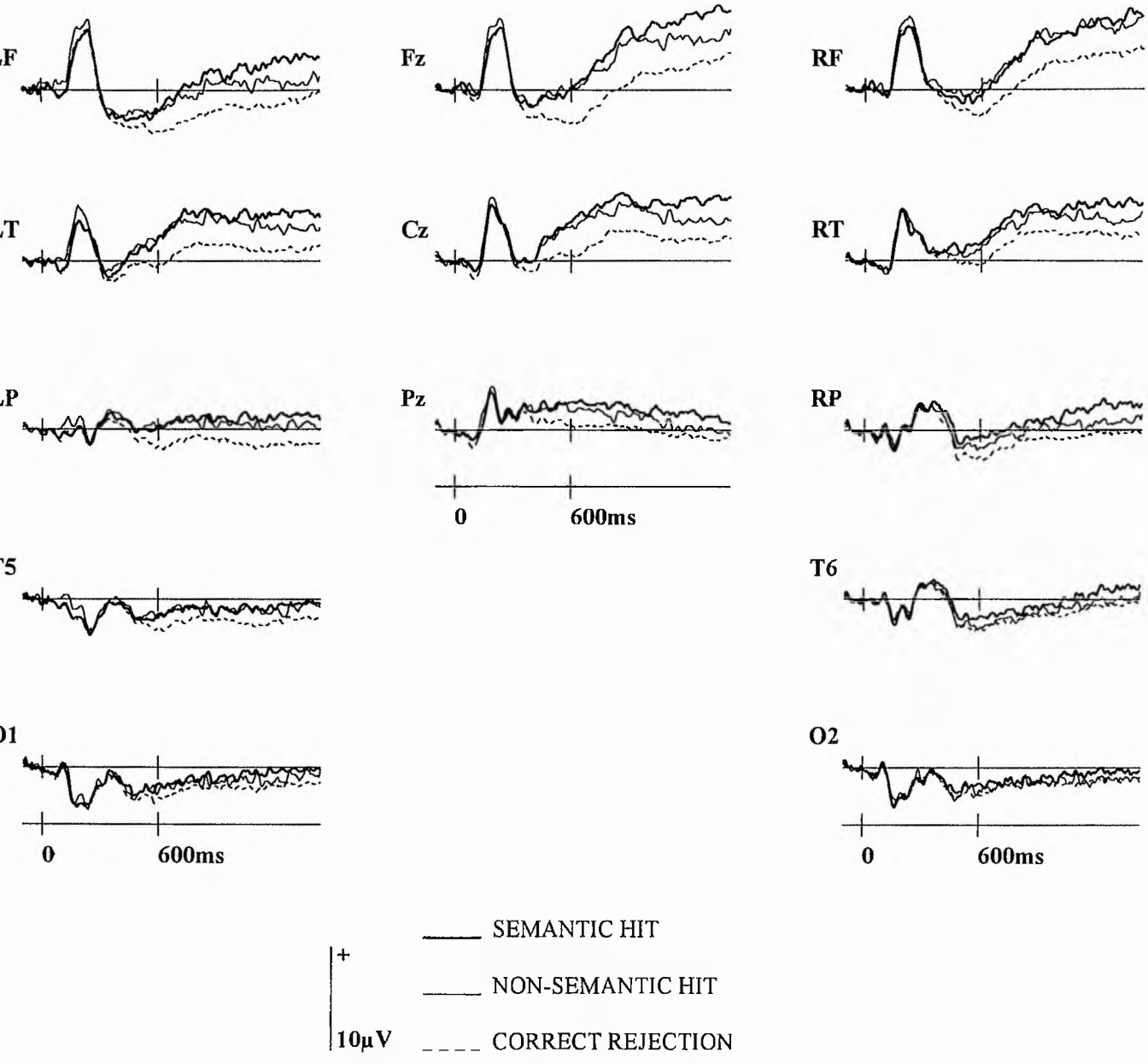


Figure 5.3 Grand average ERPs evoked by semantic hits, non-semantic hits, and correct rejections. Electrode sites as for figure 5.1.

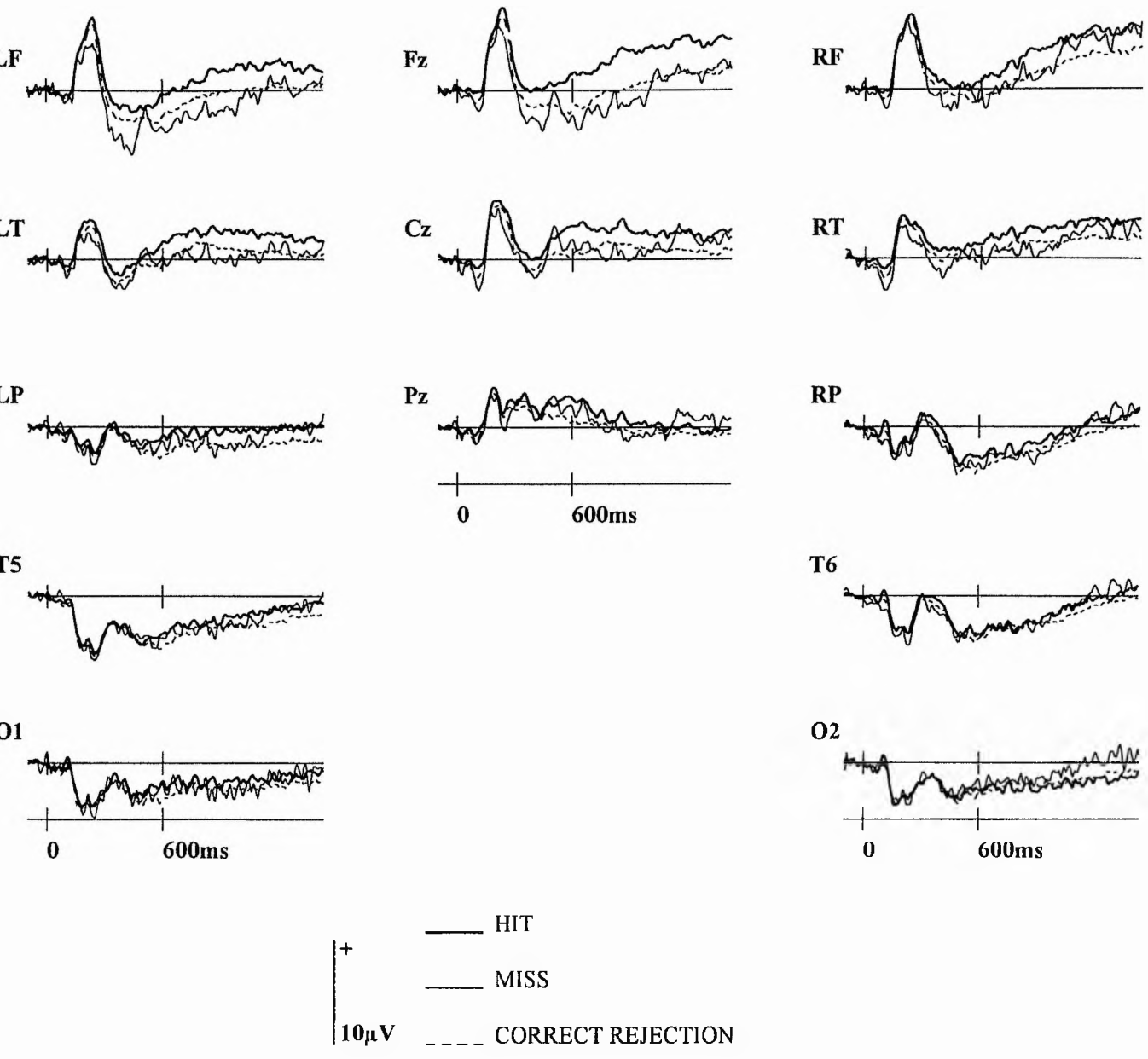


Figure 5.4 Grand average ERPs evoked by hits, misses and correct rejections. Electrode sites as for figure 5.1.

6.0 An Event-Related Potential Study of Stem Completion (1)

6.1 Introduction

The present study investigates ERP correlates of memory on the stem completion task. The experimental procedures of this study are identical to those in the previous cued recall study, with the sole exception of test phase instructions. As in the cued recall study, a depth of processing manipulation is used here to alter the probability of explicit retrieval at test. To the extent that stem completion performance reflects an intentional retrieval strategy, the probability of completion with a studied item should be affected by the depth of processing accorded to the item at study. Moreover, should it occur at all, it is likely that explicit memory will more often accompany completion with semantically, rather than non-semantically, studied items.

The present study also employed a version of the structured interview technique introduced by Schacter and colleages (see chapter 1). After each experimental session, subjects were asked a number of questions designed to determine whether or not they were 'test aware' (Bowers and Schacter, 1990; Schacter, Bowers and Booker, 1989), and if so, whether awareness affected their retrieval strategy. Specifically, subjects were asked whether they were aware of the connection between the study and test phases, and in addition, whether knowledge of the connection resulted in attempts to deliberately complete stems with studied items.

The critical ERP contrasts are between ERPs evoked by stems completed with unstudied items, and those to stems completed with semantically studied and non-semantically studied items. Any differences observed between ERPs evoked by studied and unstudied items may reflect memory-related processing. The similarity,

or otherwise, of the ERP effects observed here and the cued recall ERP effect (e.g. see figure 5.2), may reveal whether, and how, retrieval processing differs as a function of each task.

6.2 Method

6.2.1 Subjects

The subjects were 22 young healthy adults. Of these, the data from 6 were discarded because they provided insufficient artifact-free trials to form ERPs in critical conditions. Of the remaining 16 subjects, 9 were female and all were right handed. Their mean age was 22 years (range 18-30).

6.2.2 Stimuli

The experimental stimuli, and study / test phase stimulus lists, were all identical to those used in experiment 1.

6.2.3 Procedure

The study phase was identical in all respects to that of the previous cued recall experiment (see the method section of the preceding chapter). Instructions at test were to complete stems with the first suitable word to come to mind. Subjects were not informed that half of the stems belonged to studied items. On completion of each session, subjects were formally asked whether they were aware of the connection between the study and test phases of the experiment, and also whether they would admit that such knowledge had in fact affected their performance strategy. Subjects were fully debriefed once they had responded to these questions.

6.2.4 ERP Recording

See the method section of experiment 1 (Chapter 5).

6.3 Results

6.3.1 Behavioural Data

When asked whether they were test aware, all 22 subjects responded positively. When asked if they ever deliberately attempted to complete stems with studied items, all 22 subjects responded negatively.

The behavioural data are presented in table 6.1., which depicts the correct completion rate for items from each study condition, along with the baseline completion rate (the proportion of stems completed by chance with unstudied item from the experimental pool). The upper row of the table gives the behavioural data from all 22 subjects. The middle row gives the data from the 16 subjects who contributed sufficient trials with which to form ERPs in each critical condition. In each group, the proportion of stems completed with semantically studied items was larger than that for non-semantically studied items. This effect is larger in the data from the group of 16 subjects. A one-way ANOVA contrasting the correct completion rates and the baseline rate for all 22 subjects revealed a main effect of condition [$F(1.6,34.0) = 46.03$, $p < 0.001$]. Planned t-tests showed that the correct completion rates did not differ from one another, but that both were significantly larger than the baseline rate (semantically studied: $t(21) = 7.6$, $p < 0.001$; nonsemantically studied: $t(21) = 9.84$, $p < 0.001$).

The analogous ANOVA of data from the 16 subjects also gave rise to an effect of condition [$F(1.7,25.3) = 68.15$, $p < 0.001$]. However, in this case the planned t-tests revealed that while the studied item completion rates were both larger than the baseline rate (semantically studied: $t(15) = 9.51$, $p < 0.001$; nonsemantically studied: $t(15) = 10.78$, $p < 0.001$), the proportion of stems completed with semantically

studied items was significantly greater than that for non-semantically studied items ($t(15) = 2.62$, $p < 0.025$).

For comparison, the lower row of table 6.1 gives the overall correct completion rates for semantically and nonsemantically studied items from the previous cued recall experiment. The magnitude of the depth of processing effect on correct completion rates for the 16 subject group shown in the middle row of the table, is similar to that for the cued recall data. The effect of task on these performance measures (along with the baseline completion rates in each study) was analysed by ANOVA employing the factors of task (as a between subjects variable) and completion rates for semantically studied, nonsemantically studied and baseline items. No effect invoving the factor of task was significant.

6.3.2 Event-Related Potentials

6.3.2.1 ERPs to Stems Completed with Unstudied Items

Stems belonging to unstudied items could either be completed with words from the experimental item-pool (*new target ERPs*), or other words (*new non-target ERPs*). Sufficient trials were obtained from the 16 subjects to contrast ERPs evoked by stems completed with new target and new non-target items. ERPs for these two conditions are depicted in Figure 6.1. The mean number of trials contributing to these ERPs was 27.6 (20-38) and 148.1 (99-165), respectively.

As is clear from figure 6.1, new target ERPs are the more positive-going from around 400ms until around 900ms or so. This positive shift is symmetrically distributed, and present at most electrode sites. Exploratory ANOVAs carried out on data from consecutive 100ms latency regions (beginning at 300-400ms), were used to initially contrast the ERPs from these two conditions at the midline and lateral sites. These ANOVAs revealed that the differences evident in figure 6.1 were significant during the 400-800ms latency region. On the basis of these analyses, data

from the entire 400-800ms latency region was selected for further analyses, as described below.

ANOVAs of data from the midline and lateral sites during the 400-800ms latency region each gave rise to main effects of condition (midline sites: [$F(1,15) = 8.39$, $p < 0.025$]; lateral sites: [$F(1,15) = 8.60$, $p < 0.025$]). In each case, the main effects were due to the enhanced positivity of the new target ERPs relative to the new non-target ERPs.

The mere fact that subjects completed stems with experimental items appears to be sufficient to modulate ERPs on this task. One interpretation of this finding is that some unanticipated form of selection bias operated during the process of selecting stimuli for this and the previous cued recall study. If some form of item selection bias has occurred, this raises a major problem for the interpretation of the data sets from this study and the previous cued recall study [6]. As regards this study, the major problem is whether or not a suitable control condition exists, against which to contrast ERPs evoked by stems completed with studied items. Because of the possibility of an ERP modulation consequent merely on completion with an experimental item, it is not possible to use the new non-target ERPs as a control condition. If this condition were used, and significant ERP effects were observed, these could be ascribed simply to an item effect, and not memory-related processing.

One alternative strategy would be to solely contrast ERPs evoked by stems completed with studied items, as a function of study condition. This comparison would reveal whether ERPs were sensitive to the conditions under which items were studied. If any reliable ERP effects were observed, they could not be due to an item selection effect, since items were counterbalanced across the study conditions. But

[6] The critical question for the cued recall study is whether the cued recall ERP effect arose merely whenever stems were completed with items from the experimental word-pool. However, the ERP data from the 'miss' condition of that experiment are alone sufficient to refute this possibility, since in that condition, where stems were completed with implicitly retrieved study items, there was no evidence for a positive-going ERP effect (see figure 5.4). Also, further analyses of the relevant baseline conditions in that experiment revealed no differences simply as a function of whether or not stems were completed with (unstudied) experimental items.

the more powerful contrast involves comparing semantic and nonsemantic target ERPs with the new target ERPs. Any differences thus revealed could potentially isolate ERP effects associated with memory-related processing, over and above simple item effects. The results of such analyses are presented below.

6.3.2.2 Effects of Study Task

Figure 6.2 depicts the new target ERPs, along with ERPs evoked by stems completed with semantically studied (semantic target ERPs) and nonsemantically studied (nonsemantic target ERPs) items. The mean number of trials contributing to semantic and nonsemantic target ERPs were 34.8 (20-55) and 28.9 (23-39), respectively. By visual inspection alone, differences between these ERPs appear largest at the left temporal and parietal electrode sites, where the semantic target ERPs are more positive going than ERPs from the other two conditions from around 800-1100ms. Nonsemantic target ERPs also appear slightly more positive going than ERPs from the other two conditions at the midline sites during approximately 400-600ms.

A series of exploratory ANOVAs of data from consecutive 100ms latency regions (beginning at 300-400ms) were used to initially analyse ERPs in these conditions. Significant differences between ERPs in these three conditions were found only in the data from the lateral electrode sites during the 800-900ms and 900-1000ms latency region. Based on these analyses, data from the entire 800-1000ms latency region was selected for further analyses, reported below.

A global ANOVA of data from the midline sites, for all three conditions shown in figure 6.2, during the 800-1000ms latency region did not give rise to a significant effect involving the factor of condition. However, the ANOVA of data from the lateral sites gave rise to a significant condition by hemisphere by site interaction [$F(3.0, 44.8) = 3.28$, $p < 0.05$]. As noted above, inspection of figure 6.2 shows that during this latency region, at the left parietal and temporo-parietal electrode sites, semantic target ERPs are more positive-going than ERPs from the other two

conditions. The distribution of this effect resembles that of the left parietal old/new effect typically observed on tests of recognition memory (see chapter 3). In addition, the time course of the parietal old/new effect typically encompassses the 800-1000ms latency region.

Accordingly, the present interaction was further elucidated by a subsidiary ANOVA carried out upon data from the left and right parietal and temporo-parietal electrode sites. This subsidiary ANOVA gave rise to a significant condition by hemisphere interaction [$F(1.8, 27.1) = 3.80$, $p < 0.05$]. The interaction arose because at the left hemisphere sites the semantic target ERPs are much more positive-going than ERPs from the other two conditions.

6.3.3 Summary of Results

Two ERP effects were observed. The first differentiated ERPs evoked by stems completed with unstudied items, as a function of whether the completion belonged to the experimental item-pool or not. The second ERP effect differentiated ERPs evoked by stems completed with studied and unstudied items. In this case, the ERP effect took the form of a temporally restricted (800-1000ms) enhanced positivity, favouring posterior left hemisphere sites. This effect was present for ERPs evoked by stems completed with semantically studied items, relative to those evoked by stems completed with nonsemantically studied items and unstudied target items, which did not differ from one another.

6.4 Discussion

The proportion of stems completed with semantically studied items was larger than that for non-semantically studied items. A trend for this can be observed in the data from the entire 22 subjects, but the effect was only statistically reliable in the critical subset of 16 subjects who contributed ERP data. Similar findings have been observed previously (see chapter 1), and indicate that depth of processing can have

weak but significant effects on stem completion performance, even when subjects do not complete stems deliberately with studied items (given that subjects told the truth in their responses to the post-session questions).

The magnitude of the depth of processing effect seen here was comparable to that observed in the previous cued recall study for the overall completion rates (see table 6.1, lower row). Thus even when trying to complete stems with studied items (cued recall), subjects could not do so significantly more often than when completing stems with the first word which comes to mind (stem completion). The similar performance on each task is probably a consequence of the difficulty of cued recall in the previous study. Apart from the sheer number of items to be remembered (200 in total), another factor contributing to the difficulty of cued recall was the restricted time which subjects had available in which to complete stems (3s). It is likely that without this temporal restriction (which was forced by the necessity to time-lock ERP recordings to retrieval attempts), performance on the cued recall task would have been higher overall.

6.4.1 Effects of Item Selection on ERPs

ERPs evoked by stems completed with unstudied items differed as a function of whether the items belonged to the experimental item-pool (new target ERPs) or not (new non-target ERPs). New target ERPs were the more positive from around 400ms until around 800ms (see figure 6.1). The presence of an ERP effect which differentiates the new target and non-target ERPs indicates a subtle bias in the process which was used to select stimuli for this and the previous experiment. As I have already noted, no evidence was forthcoming from the previous cued recall study to suggest that mere completion with an item from the experimental word pool was sufficient to modulate ERPs, rendering the presence of this effect still more puzzling. One solution to this 'problem' is to review the selection process for stimuli, with the aim of identifying a systematic bias. The experiment which follows in the next chapter details the procedure used to generate a new set of experimental stimuli, and the replication of the present study.

6.4.2 Possible Effects of Memory on ERPs

ERPs evoked by stems completed with studied and unstudied items also differed. ERPs evoked by stems completed with semantically studied items (semantic target ERPs) were more positive-going than those evoked by stems completed with nonsemantically studied items (nonsemantic target ERPs) and new target ERPs, which did not differ from one another (see figure 6.2). This positive-going modulation was largest at left posterior electrode sites, during the 800-1000ms latency region. The scalp distribution of this effect resembled that of the left parietal old/new effect, previously observed in a number of studies investigating direct and indirect tests of memory (see chapter 3).

Despite the intriguing resemblance between the present semantic target ERP effect and the parietal old/new effect, it still remains the case that the results of the present study require replication with a new set of stimuli, created with a 'bias free' procedure. If the present results are replicable, this would obviously lend the findings more credence, and remove the possibility that the present data are confounded by the item selection bias. So, prior to any further discussion of the present findings, the replication study is presented in the following chapter.

6.5 Summary and Conclusions

The present study contrasted ERPs evoked by stems completed with studied and unstudied items on a test of stem completion. An ERP effect was found to differentiate conditions where stems were completed with unstudied items. ERPs evoked by stems completed with unstudied items which belonged to the experimental item-pool were more positive-going than ERPs evoked by stems completed with other unstudied items. No explanation for this anomalous effect could be given, except to say that it probably indicates a systematic bias in the procedures used to select stimuli for this and the previous study. Importantly, when

the relevant conditions were analysed, no such effect was observed in the previous cued recall study. This indicates an interaction between task (cued recall vs. Stem completion) and some unanticipated feature of the experimental stimuli.

An additional ERP effect was found to differentiate ERPs evoked by studied and unstudied items. This effect resembled the parietal old/new effect observed in other ERP studies of direct and indirect tests of memory. However, the reliability of this finding is open to question on the grounds that ERPs in this study differed merely as a consequence of whether items were completed with an experimental item, irrespective of whether the item had been studied. In the experiment presented in the following chapter, corrections to the procedures used to generate stimuli are derived, allowing a replication of the present experiment. The replication will allow a contrast between ERPs evoked by stem completed with studied and unstudied items which is not, potentially at least, confounded by the presence of an item selection bias which itself gives rise to an ERP modulation. The nature of this bias is discussed in the introduction section of the following chapter.

Table 6.1 Behavioural Data for experiment 2. Shown separately for all 22 experimental subjects, and the subset of 16 subjects who contributed ERP data. The percentage of stems completed with items from each study condition (Semantic vs. Nonsemantic study tasks), along with the proportion of stems completed with unstudied items from the experimental pool (representing the baseline, or chance, completion rate), are given. S.Ds in brackets.

	SEMANTIC	NONSEMANTIC	BASELINE
N=22	32.5 (12.1)	29.2 (7.9)	14.0 (3.9)
N=16	37.7 (9.3)	32.4 (5.7)	15.0 (3.5)

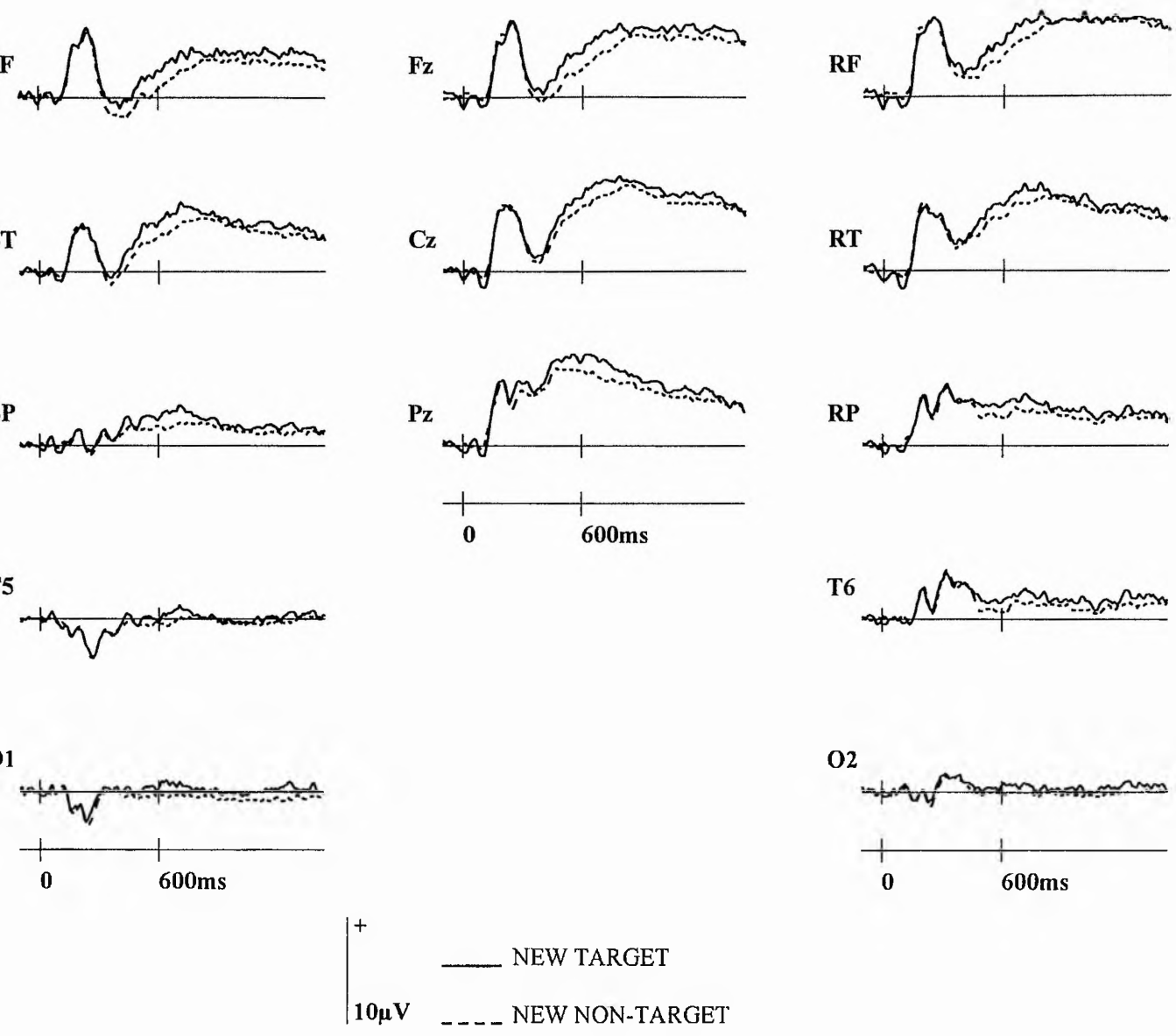


Figure 6.1 Grand average ERPs evoked by stems completed with unstudied items belonging to the experimental item pool (new target ERPs), or not (new non-target ERPs). Electrode sites as for figure 5.1.

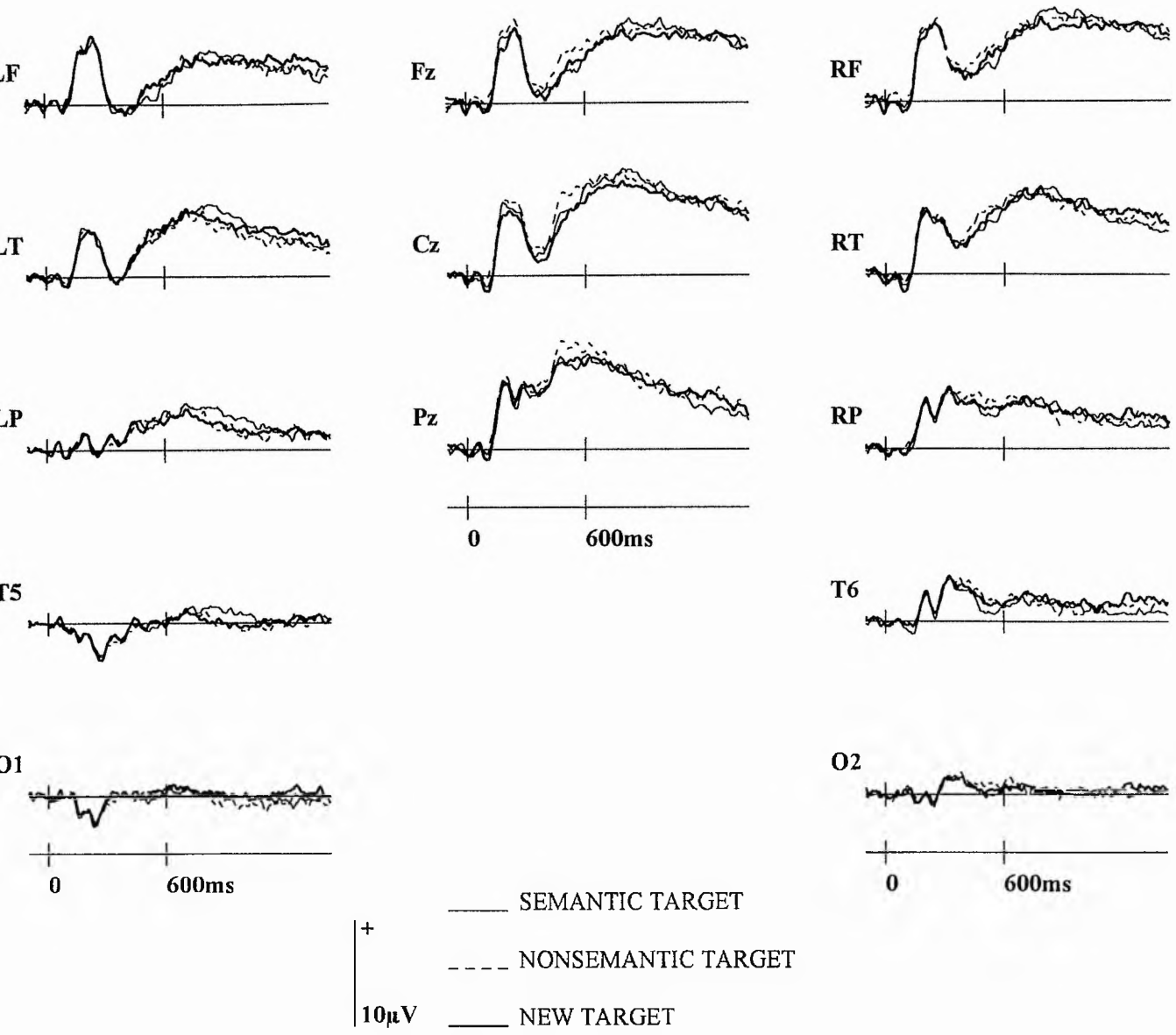


Figure 6.2 Grand average ERPs evoked by stems completed with semantically studied (semantic target ERPs) and nonsemantically studied (nonsemantic target ERPs) items, along with new target ERPs. Electrode sites as for figure 5.1.

7.0 An Event-Related Potential Study of Stem Completion (2)

7.1 Introduction

In the previous study, ERPs differed as a function of the status of *unstudied* items used to complete stems; unstudied items which belonged to the experimental pool were associated with a positive-going ERP modulation. This finding suggested that the stimulus selection procedure was systematically 'biased' in some unforseen manner. This bias differentiated experimental items from other items which could be used to complete stems. ERPs appear to be sensitive to this biasing factor, whatever it may have been.

The stimulus selection procedures, given in chapter 4, were closely scrutinised. After some thought it became clear that the procedure used to select items did not include a suitably randomised method of selecting 'target' completions for stems. The procedure involved selecting a set of unique word-stems, each belonging to at least five different English words. In total, 500 stems which matched these criteria were selected from the Francis and Kucera (1982) corpus. However, the particular target completion for each stem was *not* selected at random out of all those possible. This oversight means that a systematic item selection bias could have been introduced by the experimenter (i.e. me).

A more suitable selection procedure would have been to first select word stems, and then to compile a list of possible completions for each. Having done this, the next appropriate step would have been to select, at random, one of the possible completions for each stem, thus to form a pool of experimental stimuli. This improved procedure was adopted in the present study to select a new set of

experimental stimuli (which are given in part B of the Appendix to the thesis). The method section below details the actual implementation of the procedure.

The present study replicates the previous stem completion study, using the new set of stimuli. The critical ERP contrasts are once more between ERPs evoked by studied and unstudied items. If subjects contribute sufficient trials, it will also be possible to directly examine whether the ERPs evoked by stems completed with unstudied items no longer differ according to the status of the item.

7.2 Method

7.2.1 Subjects

Subjects were 21 young adults. Of these 21 subjects, the data from 5 were discarded because they provided insufficient trials to form ERPs in critical conditions. Of the remaining 16 subjects, 9 were female and all were right handed. Their mean age was 21.2yrs (range 18-28).

7.2.2 Stimuli

A list of possible completions for each of the 500 stems in the experimental pool was formed. This list contained at least 5 and not more than 10 completions for each stem. A target completion was selected at random for each stem and used to create a new pool of 500 experimental stimuli. A computer program was written for this purpose. The program used a (pseudo) random number generator to pick out a single item as a completion to each stem, from the list of possible completions.

Experimental items were selected at random from the new pool of 500 items. Each item was between four and nine letters in length. All procedures used to form study and test phase item lists were identical to those for the previous two experiments.

7.2.3 Procedure

The experimental procedure was identical to that given in the method section of experiment 2 above.

7.2.4 ERP Recording

All aspects of EEG recording were identical to those for experiments 1 and 2.

7.3 Results

7.3.1 Behavioural Data

All subjects were test-aware. All subjects responded negatively when asked if they ever deliberately attempted to complete stems with studied items.

Table 7.1 summarises the behavioural data. For all 21 subjects, a global one-way ANOVA of the baseline and correct completion rates for studied items gave rise to a significant effect [$F(1.9, 37.1) = 74.6$, $p < 0.001$]. Planned t-tests showed that the proportion of stems completed with semantically and nonsemantically studied items did not differ significantly, while each was significantly larger than the baseline completion rate (semantically studied: $t(20) = 10.07$, $p < 0.001$; nonsemantically studied: $t(20) = 11.15$, $p < 0.001$). The analogous ANOVA and planned comparisons employing data from the 16 subject group gave rise to an identical pattern of results.

7.3.2 Event-Related Potentials

7.3.2.1 ERPs to Stems Completed with Unstudied Items

Of all the 21 subjects, only 10 contributed sufficient trials with which to form separate ERPs for conditions where stems were completed with unstudied experimental items (*new target ERPs*) vs. other unstudied items (*new non-target ERPs*). Figure 7.1 depicts the grand average new target and non-target ERPs, from

these 10 subjects. The mean number of trials contributing to these ERPs was 18.5 (16-21) and 163.3 (130-178), respectively.

Figure 7.1 shows that the new target and non-target ERPs do not appear to differ at any electrode site. This was confirmed by the results of a series of exploratory ANOVAs of data from the midline and lateral sites, covering consecutive 100ms latency regions, beginning at 100-200ms. No significant effects involving the factor of condition were observed.

The above analyses suggest that the item selection problem has been rectified by the selection procedures adopted in this study. It is therefore possible to collapse together the new target and new non-target ERPs to form a single *new item ERP* condition. The following section details the results of contrasts between the new item ERPs, and ERPs evoked by stems completed with studied items.

7.3.2.2 Effects of Study Task

Figure 7.2 depicts the grand average semantic and nonsemantic target ERPs, along with the new item ERPs, from the 16 contributing subjects. The mean number of trials contributing to these ERPs was 24 (16-38), 20.5 (16-28) and 180 (149-198), respectively. Visual inspection of figure 7.2 shows that two distinct ERP modulations differentiate the ERPs from these conditions. First, the magnitude of the second positive peak of the ERP (i.e. the P2) differs as a function of condition. The P2 is largest in semantic target ERPs, and smallest in nonsemantic target ERPs. This P2 effect is restricted to anterior electrode sites, particularly over the left hemisphere.

Semantic target ERPs also differ from ERPs in the other two conditions in respect of a more widely distributed positive-going modulation, present from around 400ms until the end of the recording epoch. Nonsemantic target ERPs and new item ERPs do not differ from one another during this latency region. The distribution of this late positive shift is more symmetrical than that observed for semantic target ERPs in the previous stem completion experiment (see figure 6.2). However, the present effect

does resemble the cued recall ERP effect observed in experiment 1 (e.g. see figure 5.2).

7.3.2.2.1 The P2 Effect

The following procedure was used to analyse the observed P2 effect. First, the P2 peak latency was determined using an ERP peak detection program, based on measures taken from the grand averaged waveforms from each condition shown in figure 7.2. The latency at which the peak P2 occurred was thus confirmed to be approximately 200ms. Data from the 150-250ms latency region, encompassing the region in which the P2 modulation occurred, was selected for further analyses. Initially, global ANOVAs of data from this latency region, for all three conditions depicted in figure 7.2, were carried out. Separate analyses were conducted on data from the midline and the lateral electrode sites. All ANOVAs employed the factors of condition and site, with the additional factor of hemisphere in analyses of data from lateral sites.

The global ANOVA of data from the midline sites gave rise to no significant effects involving condition. The global ANOVA of data from the lateral sites gave rise to a significant interaction between condition, hemisphere and site [$F(3.2, 47.8) = 2.92$, $p < 0.05$]. By inspection of figure 7.2, it would appear that this interaction arises because the P2 modulation, as a function of these conditions, is largest at the left and right frontal and anterior temporal electrode sites. Accordingly, the interaction was elucidated by a series of subsidiary pairwise ANOVAs, carried out on data from just these frontal and anterior temporal sites. The subsidiary ANOVAs employed the factors of condition, hemisphere and site (LF,LT,RF,RT).

The subsidiary ANOVA contrasting the semantic target and new item ERPs gave rise to a condition by site interaction which just failed of significance [$F(1,15) = 3.72$, $p < 0.055$]. As inspection of figure 7.2 shows, the trend in the data is for differences in P2 magnitude to be larger at the frontal than the anterior temporal

electrode sites. The P2 in semantic target ERPs being larger than that for the new item ERPs.

The subsidiary ANOVA contrasting the nonsemantic target and new item ERPs gave rise to a significant condition by hemisphere interaction [$F(1,15) = 7.90$, $p < 0.025$]. In this case, the interaction reflects a crossover effect, whereby the P2 magnitude in nonsemantic target ERPs is reduced compared to new item ERPs at left hemisphere sites, but is larger over the right hemisphere sites.

The subsidiary ANOVA contrasting the semantic and nonsemantic target ERPs also gave rise to a significant condition by hemisphere interaction [$F(1,15) = 21.92$, $p < 0.001$], and in addition a significant condition by site interaction [$F(1,15) = 4.61$, $p < 0.05$]. These interactions arose because the P2 enhancement in semantic target ERPs was largest at left hemisphere sites, and also tended to be larger at the frontal than the anterior temporal electrodes.

7.3.2.2.2 The Late Positive Effect

The late positive effect evident in semantic target ERPs (see figure 7.2) was initially analysed by a series of exploratory ANOVAs of data from consecutive 100ms latency regions, beginning at 300-400ms. The ANOVAs used data from all three conditions shown in figure 7.2, with separate ANOVAs conducted on data from the midline and the lateral electrode sites. All ANOVAs employed the factors of condition and site, with the additional factor of hemisphere in ANOVAs of the data from the lateral sites. For data from the midline sites, a reasonably consistent pattern of main effects of condition occurred throughout the 400-1434ms latency region. The effects were strongest and most consistently present during the 400-900ms latency region. No significant effects involving the factor of condition were found for data from the lateral sites during any 100ms latency region. On the basis of these analyses, a more broad latency region encompassing 400-900ms was selected for further detailed analysis, as described below.

An initial global ANOVA of data from the midline sites during the entire 400-900ms latency region gave rise to a significant main effect of condition [$F(1,4, 21,1) = 4.05$, $p < 0.05$]. Post-hoc analyses showed that the semantic target ERPs were significantly more positive-going than ERPs in either of the two other conditions, which did not differ from one another.

No significant effects involving the factor of condition were observed in ANOVAs of data from the lateral electrode sites during the 400-900ms latency region. Though, as figure 7.2 shows, semantic target ERPs at the lateral sites are more positive-going than nonsemantic target and new item ERPs, which do not appear to differ from one another.

7.3.3 Summary of Results

Two distinct effects were observed to differentiate ERPs evoked by stems completed with studied and unstudied items. First, the P2 peak in semantic target ERPs was enhanced at anterior electrode sites, relative to that for the nonsemantic target and new item ERPs. The reduction of the P2 observed in nonsemantic target ERPs was most marked at left anterior frontal sites. A later positive-going modulation was also observed in semantic target ERPs, relative to nonsemantic target and new item ERPs which did not differ from one another subsequent to the initial P2 modulations. This positive-going shift was only statistically reliable at the midline electrode sites, though a similar positive-going modulation was also evident at the lateral electrodes.

7.4 Discussion

7.4.1 Behavioural Data

First of all I will discuss whether the changes in the item selection procedures achieved their purpose. Critically, ERPs in this study were not modulated simply as a function of whether or not stems were completed with experimental items (see figure

7.1). This finding indicates that the previously observed ERP modulation due to completion with items from the experimental pool is not a feature of the ERP data in this experiment. The changes to the item selection procedures were therefore a success. In addition, the baseline completion rate for the new set of stimuli was found to be reduced relative to that for the old set (from approximately 14.0% to 8.0%). The difference in baseline completion rates indicates that, on average, items from the old set of stimuli come to mind more often than items from the new set of stimuli, as completions for their stems.

As in the previous stem completion study, all subjects in this experiment were test-aware, but claimed not to have changed their retrieval strategy as a consequence of this. Consistent with this, the probability of completing stems with studied items was not affected by the depth of processing accorded to items at study. This finding contrasts with that observed in the previous stem completion experiment, where prior study with the semantic task was associated with an increased probability of correct completion. In any case, the present behavioural data suggest that retrieval of studied items in the present experiment was involuntary.

7.4.2 ERPs and Item Selection Effects

The purpose of the present study was to assess whether or not the ERP findings of the previous stem completion study were reliable when item selection procedures were corrected for possible sources of bias. This study was deemed necessary not least because a possible ERP correlate of memory was identified in the previous study. This ERP effect resembled the parietally distributed ERP 'old/new' effect (e.g. Rugg and Doyle, 1992). However, the memory-based interpretation of the ERP effect observed in the previous study was predicated on the assumption that relevant ERP contrasts were unconfounded by the item selection artifact. The critical question is: when the potential for this confound is removed, as in the present study, will the ERP effect remain?

However, the ERP effects observed here did not replicate those found in the previous stem completion experiment. Specifically, the ERP effect observed for semantic target ERPs in the previous study was confined to posterior left hemisphere sites during the 800-1000ms latency region (see figure 6.3). No such effect was observed here (see below for more detailed discussion of the present ERP findings). It therefore seems appropriate to treat the findings of the previous study as potentially confounded by the item selection bais. The remainder of this discussion therefore focuses on the present ERP results.

7.4.3 ERPs and Involuntary Explicit Retrieval

Two memory-related ERP effects were observed in the present study. I will discuss the late positive shift first. ERPs evoked by stem completed with semantically studied items (semantic target ERPs) were more positive-going than ERPs evoked by stems completed with nonsemantically studied (nonsemantic target ERPs) and unstudied items (new item ERPs). This effect was statistically significant only at midline sites during the 400-900ms latency region. This late positive shift resembles the cued recall ERP effect reported in experiment 1 (e.g. see figure 5.1). However, the effect was much reduced in the present study. The late positive shift was also absent in nonsemantic target ERPs. This finding is analogous to that observed in the previous cued recall study, where the cued recall ERP effect was absent in ERPs evoked by stems completed with nonsemantically studied items when ERPs were formed irrespective of the nature of item retrieval (i.e. explicit or implicit, see figure 5.1).

As argued above in chapter 5, the cued recall ERP effect reflects processes associated with explicit retrieval. The late positive shift observed here may thus also reflect explicit retrieval accompanying correct completion with semantically studied items. The relative weakness of the late positive shift in the present study therefore indicates that explicit retrieval did not accompany correct completion with semantically studied items as often as was the case in the cued recall study. The absence of this effect in nonsemantic target ERPs in turn indicates that the

probability of explicit retrieval was even more reduced for items studied with the nonsemantic task.

In conjunction, the present behavioural and ERP data represent a dissociation between different measures of memory. The behavioural data indicated that levels of priming (i.e. enhanced rates of completion with studied vs. unstudied items) were not significantly affected by the processing accorded to items at study. This finding also indicates that retrieval of studied items was involuntary. In contrast, the late positive shift in ERPs, interpreted as reflecting (involuntary) explicit memory for studied items, was sensitive to study depth of processing. These findings provide support for the notion that priming and explicit memory depend upon functionally distinct processes. The findings also support the notion that the brain regions mediating priming and explicit retrieval are distinct.

7.4.4 ERPs and Implicit Retrieval

The amplitude of the P2 peak was also found to be sensitive to the status of the items used to complete stems (see figure 7.2). P2 amplitude was significantly reduced at left anterior electrode sites in nonsemantic target ERPs, relative to semantic target ERPs. The P2 amplitude was thus found to be sensitive to the conditions under which items were studied. In contrast, a more symmetrical P2 enhancement was observed for semantic target ERPs relative to the P2 in new item ERPs.

The exact functional significance of the P2 modulation is not clear. In previous studies, modulations of the P2 have been shown to reflect physical characteristics of visually presented stimuli, such as differences in the length of words eliciting ERPs (e.g. Young, 1990, unpublished doctoral thesis). On the basis of such findings, the P2 can be considered an exogenous ERP component (see chapter 2). However, since the physical characteristics of evoking stimuli did not differ as a function of condition in this study, such interpretations do not seem appropriate in the present case.

It is possible that the P2 modulation could reflect memory-related processing. This conclusion rests primarily on the finding that P2 amplitude was modulated according to whether stems were completed with studied or unstudied items. Thus, the processes reflected by the P2 modulation were differentially active according to whether stems were completed with studied items or not. In addition, P2 amplitude was sensitive to the conditions under which items were studied. As argued above in chapter 5, sensitivity to study depth of processing indicates that the ERP effect reflects either explicit retrieval, or implicit conceptual priming.

In order to give a more precise functional interpretation of the P2 effect, it is therefore necessary to consider whether the effect is more likely to reflect explicit or implicit retrieval.The P2 effect appears to differ markedly in its scalp distribution from that of the late positive shift. The P2 effect was largely confined to anterior left hemisphere sites, whereas the late positive shift was maximal over the midline electrode sites. This strongly suggests that the brain regions generating the P2 effect differ from those generating the later, more temporally extended and widespread, positive-going modulation. The P2 modulation and the late positive shift may therefore reflect processes instantiated within different brain regions. Hence, the processes reflected by each effect may also be functionally distinct. This conclusion is made only tentatively, since it may be the case that the processes reflected by the P2 modulation play some role in explicit retrieval. However, it should be noted that no P2 modulation was observed in the previous cued recall study where explicit retrieval was certainly a more frequent occurrence.

7.5 Summary and Conclusions

Correct completion of stems with studied items was associated with two distinct ERP modulations. A positive-going modulation present in ERPs evoked by stems completed with semantically studied items was associated with involuntary explicit memory accompanying retrieval of these items. The probability of explicit retrieval was significantly reduced for nonsemantically studied items, as indicated by the

elimination of the ERP effect in this condition. In contrast to the ERP measures of performance, behavioural measures indicated that levels of priming were not significantly affected by the processing accorded to items at study. Thus, priming and explicit retrieval appear to depend upon functionally distinct neural mechanisms. An additional ERP effect was observed, which took the form of a modulation of the P2 component. The functional interpretation of this effect was less clear, however it is possible that this effect reflects memory-related processing which is independent of explicit retrieval. More precisely, the P2 modulation may reflect processes associated with implicit conceptual priming.

7.6 General Discussion (Experiments 1, 2 and 3)

A modified version of standard cued recall instructions was employed in experiment 1 to obtain pure measures of explicit and implicit retrieval on the task. In contrast, in experiments 2 and 3, behavioural and ERP measures of task performance were used in conjunction to provide evidence for the independence of the processes mediating behavioural priming and those reflected by ERP effects. The data from experiment 2, however, were probably contaminated by an unforseen stimulus selection bias which interacted with the conditions of that experiment, but did not appear to have an effect in experiment 1. The data from experiment 2 will not be discussed further.

All three experiments employed a depth of processing study manipulation to gain control over the probability of explicit retrieval at test. This manipulation had large and reliable effects on performance on the cued recall task. Nearly half (45%) of all correct completions with nonsemantically studied items on cued recall were not accompanied by explicit memory, as judged by recognition failure. In contrast, 95% of semantically studied items were retrieved explicitly. It is obvious that the inclusion of an overt recognition judgment in the present study allowed a more fine discrimination to be made concerning the nature of retrieval processing associated with the generation of correct completions on cued recall. Hence, pure measures of

implicit and explicit retrieval were obtained, which in turn allowed ERPs to be formed for conditions where each kind of retrieval occurred.

The depth of processing manipulation had no effect on behavioural measures of priming on the stem completion task. This indicates that subjects on the stem completion task were not deliberately trying to retrieve studied items. Had they done so, a depth of processing effect would have been evident, as for cued recall. Retrieval of studied items on the stem completion task was thus involuntary.

The explicit retrieval of studied items on the cued recall task was associated with a temporally sustained symmetrically distributed positive shift which onset around 350ms and continued unabated for around a further 1s (e.g. see figure 5.2). A similar effect, much reduced in magnitude, was observed in experiment 3, though only in ERPs evoked by stems correctly completed with semantically studied items. The ERP effect observed in experiment 3 was thus sensitive to the depth of processing manipulation, unlike the behavioural measure of priming on the task. This dissociation between the behavioural and ERP measures of performance provides further support for the conclusion, made on the basis of the findings of experiment 1, that the observed late positive shift reflects explicit memory.

In addition, the finding that separate P2 and late positive-going ERP effects occurred for stem completion in experiment 3 indicates that multiple processes are associated with studied item retrieval on the stem completion task. While the present data do not necessitate the conclusion that the P2 and late positive shifts reflect processes associated with different forms of memory retrieval, the data are consistent with this view. Further research is needed to explore the relationship between the P2 and late positive effects, with the aim of better characterising their scalp distributions in order to show that each is in fact dependent upon distinct neural generators. Further research is also needed to clarify the functional significance of the P2 effect. One interesting possibility in this regard would be to carry out ERP studies involving conceptual priming tasks (e.g. the category exemplar production task (e.g. Blaxton, 1989). If the P2 effect does reflect conceptual priming independent of explicit

retrieval, then this P2 modulation may be observed on task were conceptual priming is specifically tested.

7.6.1 Old/new ERP Effects and the Cued Recall ERP Effect

There is no sign in the ERP data from the cued recall and stem completion studies of the ERP 'old/new' effect - the asymmetric parietally distributed difference between ERPs evoked by correctly identified old and new words on tests of recognition memory (see chapter 3). The absence of this effect suggests that rather than being a general reflection of the recollection of a study episode, the parietal old/new effect may instead reflect processes more specifically tied to recognition memory. The question then arises why the topography of the cued recall effect should (apparently) differ so markedly from the old/new effects associated with recognition memory.

It should be noted at the outset that entirely separate generator populations may not underlie the two classes of ERP effect: it is entirely possible that the same set of generators are activated in both tasks, but that the cued recall effect receives a contribution from additional generators that are not engaged by recognition memory. One possibility is that the more symmetrical cued recall and stem completion late positivities reflect a difference in the subjective probability which subjects assigned to different classes of response on each task. For example, in the cued recall task used in experiment 1, the probability of an 'old' response per se (0.24) was much lower than that for a 'new' response (0.76). It could therefore be that an asymmetric old/new effect present for cued recall was 'swamped' by a topographically more symmetrical 'oddball' effect, reflecting perhaps the contribution of the probability-sensitive P300 component (see chapter 3).

However, this possibility can be discounted on two grounds. First, a strongly asymmetric old/new effect has been reported in a recognition memory 'exclusion' task for items belonging to a response category with a probability of .28, a level comparable to the proportion of old responses in the present cued recall task (Wilding and Rugg, in press). Second, in experiment 1 ERPs were obtained for

stems attracting 'false alarms' (completions with unstudied words that were falsely endorsed as old). Although such items belonged to the same response category as did those stems that were correctly completed and called old, the resulting ERPs did not differ from the ERPs that were elicited by stems whose completions were endorsed as new. Thus, membership of a relatively rare response category is not a sufficient condition for a word stem to give rise to a cued recall ERP effect, and presumably therefore the late positive shift observed for stem completion in experiment 3.

The cued recall ERP effect bears slightly more resemblance to the frontally distributed effect identified by Wilding and colleagues (e.g. Wilding and Rugg, 1996) in studies of source memory. As noted in chapter 3, Wilding and colleagues observed that frontally distributed differences between ERPs evoked by new words and words correctly judged old were considerably larger for words attracting accurate rather than innaccurate source judgments (Wilding and Rugg, 1996). This effect was significantly larger over right than left frontal electrodes, and was not present at more posterior electrode sites. The hemispheric asymmetry and more restricted frontal distribution of the effect observed by Wilding and Rugg differentiate it from the positive-going ERP effect observed for cued recall and stem completion. Nevertheless, the cued recall effect and frontal effect have quite similar time courses, and each takes the form of a positive-going ERP modulation associated with explicit retrieval. This alone indicates that similar *electrophysiological* processes, possibly involving different brain regions, generate the positive-going ERP modulations linked with explicit memory on cued recall, stem completion and recognition memory.

It is possible that the cued recall and recognition memory ERP effects may differ because the brain activity associated with memory retrieval varies according to the cue (whole item vs stem) that guides the retrieval operation. For example, according to the framework put forward by Tulving and colleagues (e.g. Tulving, 1983), retrieval is the outcome of an 'ecphoric' process in which cue information interacts with a memory trace of the learning episode, resulting in awareness of attributes of the episode. According to the current proposals given in chapter 1, this process

depends upon interactions between a 'core' memory system, centred on the hippocampus and associated medial temporal and diencephalic structures, and disparate cortical regions that represent different attributes of the encoded event. On the assumption that different retrieval cues lead to the activation and recovery of different combinations of attributes of a prior event, the present findings fit well with these proposals.

7.6.2 The Neural Generators of the Cued Recall ERP Effect

The frontally maximal scalp distribution of the ERP effects observed for cued recall and stem completion is consistent with, though by no means conclusive evidence for, the proposal that the differences reflect changes in the neural activity of one or more regions of the frontal lobe. While there is at present no direct evidence to support this proposal, recent neuroimaging (PET) studies have shown that regions of prefrontal cortex are activated during cued recall (e.g Buckner et al., 1995). There is at present some debate about the functional significance of these prefrontal PET activations, in particular as to whether they reflect retrieval success or retrieval effort per se (e.g. Rugg et al., in press(a); Kapur et al., 1994; Schacter et al., 1996). Until more is known about the neural generators of the present ERP effects, it remains unclear whether they should be considered as a neurophysiological correlate of these PET activations. This point is taken up again in the general discussion at the end of the thesis (chapter 11).

7.6.3 Summary and Conclusions

Experiment 1 provided the first report of a cued recall ERP effect which dissociates cued recall with and without explicit retrieval. The cued recall ERP effect appears to differ from previously observed ERP effects associated with explicit retrieval on other direct and indirect tests of memory. Reasons for this difference are not clear, and require further investigation. Clearly, further ERP studies of the stem completion task are also indicated. In particular, it is necessary to replicate the present experiment 3 using a larger electrode montage to better characterise and

contrast the distributions of the P2 and late positive shifts observed for stems completed with studied vs. unstudied items. The similarity of the ERP effects observed for cued recall and stem completion in experiments 1 and 3 suggests that similar processes may be reflected by the ERPs on each task.

The focus of the next two studies presented in the thesis is on the contrast between ERP correlates of explicit retrieval on cued recall and recognition memory. The purpose of these studies is to determine whether there is a genuine difference between the ERP effects observed on each task, or if this difference reflect procedural differences which confound across experiment comparisons of the ERP effects for each task.

Table 7.1 Behavioural data for experiment 3. Shown separately for all 21 experimental subjects, and the subset of 16 subjects who contributed ERP data. The percentage of stems completed with items from each study condition (Semantic vs. Nonsemantic study tasks), along with the proportion of stems completed with unstudied items from the experimental pool (representing the baseline, or chance, completion rate), are given. S.Ds in brackets.

	SEMANTIC	NONSEMANTIC	BASELINE
N=21	23.1 (6.9)	21.1 (5.3)	8.4 (1.8)
N=16	24.7 (7.0)	22.1 (4.0)	8.7 (1.8)

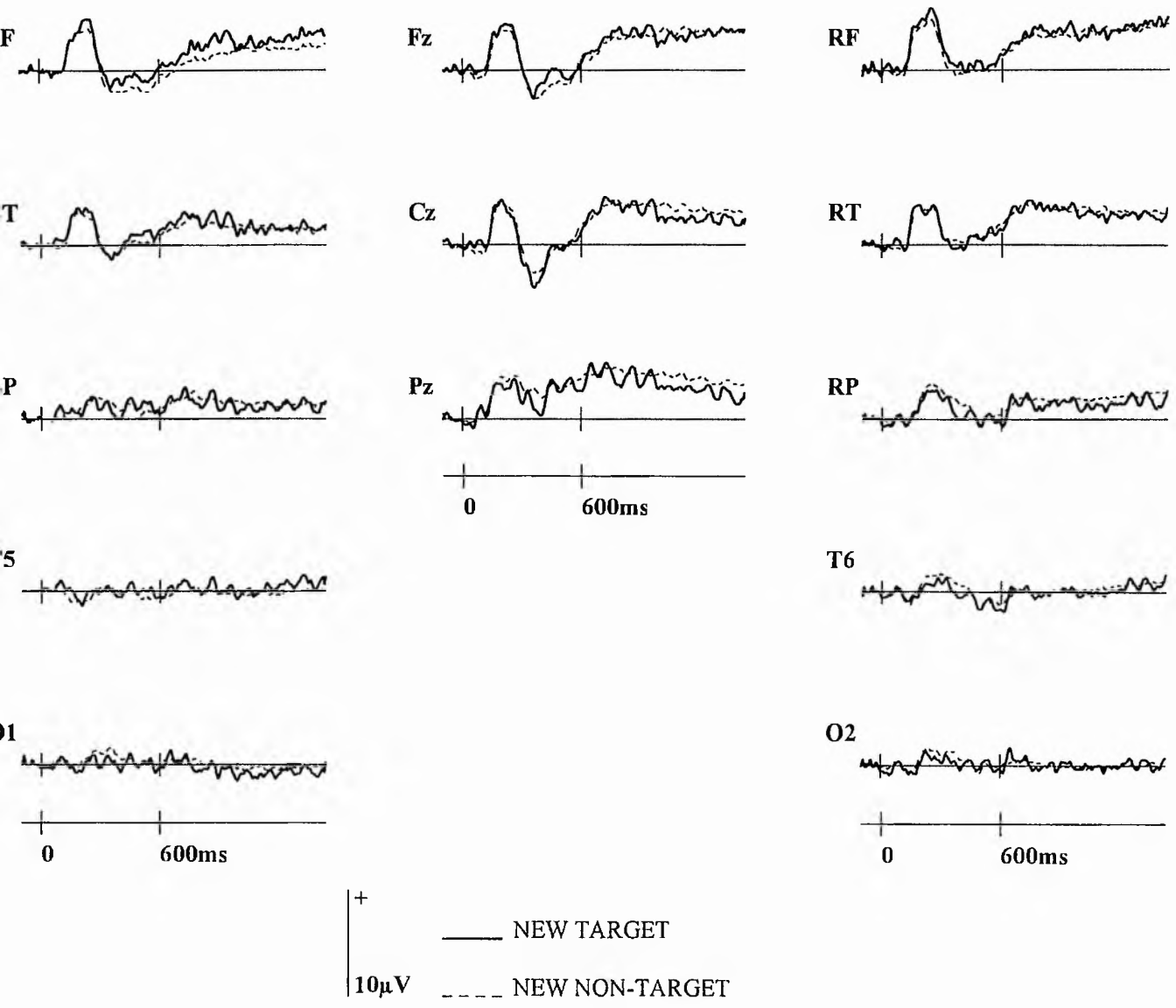


Figure 7.1 Grand average ERPs evoked by stems completed with unstudied items belonging to the experimental item pool (new target ERPs), or not (new non-target ERPs). Electrode sites as for figure 5.1.

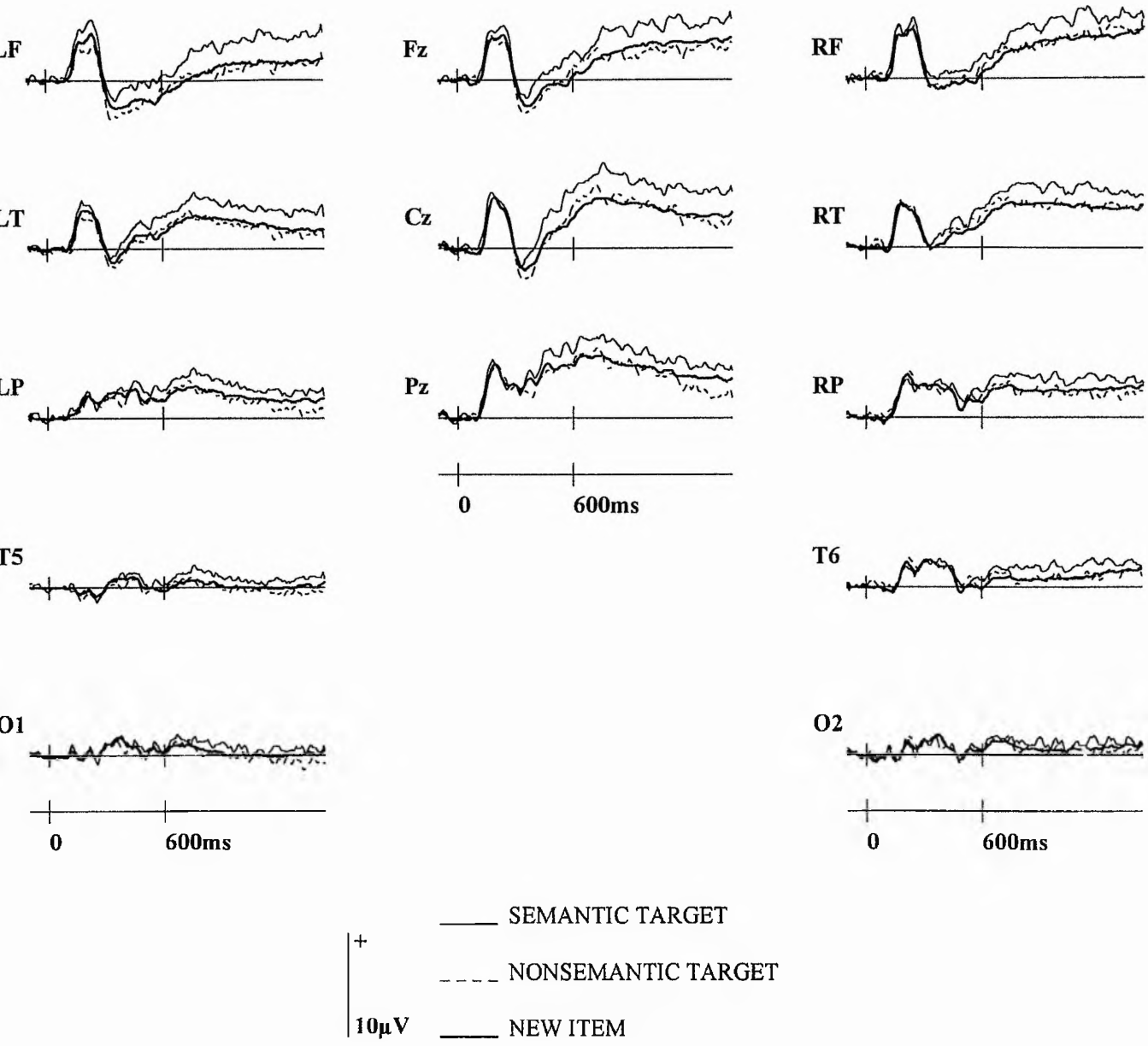


Figure 7.2 Grand average ERPs evoked by stems completed with semantically studied (semantic target ERPs) and nonsemantically studied (nonsemantic target ERPs) items, along with ERPs evoked by stems completed with unstudied items (new item ERPs). Electrode sites as for figure 5.1.

8.0 Event-Related Potential Correlates of Explicit Retrieval on Tests of Cued Recall and Recognition Memory (1)

8.1 General Introduction (Experiments 4 and 5)

In experiments 1, 2 and 3, a study depth of processing manipulation was used to alter the probability of explicit retrieval of studied items at test. The effects of this manipulation on the neural activity associated with successful retrieval was investigated using event-related potentials. In conjunction, the ERP findings of experiments 1 and 3 provided some support for the notion that the brain regions supporting explicit and implicit retrieval are not identical. This notion is a cornerstone of current theorising on retrieval processes of long term memory.

The aim of the present study (and the next study given in chapter 9) is to contrast ERP effects associated with explicit retrieval on cued recall and recognition memory. These two tasks are widely employed as measures of explicit retrieval. There exists a great deal of debate concerning the relationship between the processes engaged by tests of recall and recognition memory (e.g. see Brown, 1975; Haist, Shimamura and Squire, 1992; Hirst et al., 1986; Hirst et al, 1988). The present study (and the next study) therefore also aim to provide new information concerning whether the particular test of word-stem cued recall engages similar processes to those engaged by recognition memory. As a function of task, the nature of retrieval cues is manipulated (word-stems vs. whole word 'copy' cues). These two studies will therefore determine whether explicit retrieval cued by different forms of retrieval cue is associated with qualitatively different patterns of brain activity.

The sensitivity of retrieval processes to the nature of retrieval cues is indicated by the 'transfer appropriate processing' (TAP) account of memory. As argued in Chapter 1,

retrieval cues may affect memory because they predispose subjects to use certain kinds of processes during performance at test. Thus, for example, providing cues which are semantically related to studied items (e.g. EAGLE as a retrieval cue for BIRD), may engender more conceptually driven processing than cues related graphemically to studied items (e.g. BARD). In so far as such alterations result in the engagement of different brain regions during retrieval and subsequent post-retrieval processing, then ERP correlates of successful retrieval may have qualitatively different scalp distributions as a function of the type of cue.

According to the premises given in Chapter 2, the observation of qualitative differences in scalp distribution between two ERP effects is evidence for the contribution of functionally distinct processes to each effect, possibly instantiated by different brain regions. It is important to note, though, that the apparent differences in scalp topography between the old/new ERP effect and the cued recall ERP effect need not reflect functional differences in memory processes engaged on each task. Rather, these differences may reflect procedural differences across studies. For example, the nature of study processing, response demands at test, etc. The two studies presented here thus attempt to equate all aspects of experimental procedure apart from the nature of retrieval cues (and associated task instructions). By so doing, a contrast between ERP effects as a function of task can be made which is unconfounded by purely procedural differences on each task.

8.2 Introduction (Experiment 4)

In the previous ERP study of cued recall (experiment 1), all responses at test were given following a three second period for response preparation which followed stimulus onset. In contrast, in all but one previous study of recognition memory, responses took the form of button presses which were to be made as quickly (and as accurately) as possible. This is perhaps the major purely procedural difference between the cued recall study and the studies of recognition memory.

In one previous ERP study of recognition memory (Smith, 1993), subjects were instructed to wait for a period of 2s before responding. This study, which was reviewed in more detail in chapter 3, thus conforms more closely to the procedures of experiment 1. However, Smith found only a parietal old/new ERP effect, which differentiated ERPs evoked by recognised old and correctly rejected new items. Thus, manipulating the nature of response requirements would appear to have little effect upon the ERP correlate of explicit memory on a test of recognition memory.

In the present study, the aim is to implement tests of cued recall and recognition memory in a manner which attempts to equate all aspects of experimental procedure, aside from the nature of retrieval cues and associated task instructions. As a means of equating response demands, in the present study subjects were instructed to use button presses to indicate the type of response deemed appropriate for each item. This type of response requirement, as noted above, is typical of most previous ERP studies of recognition memory. For cued recall, subjects were instructed to complete stems with studied items. If they could do this, they were further instructed to press a given button. If stems could not be completed with a studied item, then another button was to be pressed. By manipulating whether a given stem could be completed with studied items, this response procedure allows the formation of ERPs for conditions where stems are considered, correctly or incorrectly, to belong to studied or unstudied items.

Finally, the present study also utilised a larger number of electrodes (25 in total, see figure 4.1) than has hitherto been used in the studies presented in the thesis. This larger electrode montage was used to provide a better measure of the spatial distribution of the ERP effects obtained from each task. This will in turn allow a more fine grained contrast between the topographies of any observed ERP effects.

8.3 Method

8.3.1 Subjects

Subjects were 22 young adults, each paid £3.50 per hour. The data from 6 subjects were not used to form ERPs. Of these 6 subjects, 3 did not complete the experiment. The remaining 3 did not provide sufficient trials in critical conditions with which to form ERPs. Of the remaining 16 subjects, 13 were female and all were right handed. The mean age of all 19 subjects was 19.6yrs (range 17-25). All subjects were native English speakers, with normal or corrected-to-normal eyesight.

8.3.2 Stimuli

The stimuli were drawn from the new set of 500 stimuli generated for experiment 3 (see chapter 7), and consisted of a pool of 360 critical words. The pool of 360 words was partitioned at random into two sets of 180 critical items. Half of the subjects studied one set of critical items, and the remaining subjects studied the other set. Each set of 180 items thus formed the basis of a study list. Two buffer items were included at the beginning and the end of each list. Two different orderings of critical items in each study list were created to remove item order effects, giving four study lists in total.

2 test lists were formed, comprising 360 critical items, of which 180 were 'old' items, and 180 were the unstudied ('new') set of items. The presentation format of test items (as a word or a stem), and item order, were counterbalanced across test lists. Thus, four versions of each test list were created. Each test list thus comprised 180 words (90 studied), 180 stems (90 belonging to studied items) and 2 buffer items at the beginning of each list (one word and one stem).

Stimuli were presented at both study and test in upper case on a TV monitor (white on a black background). Word stimuli subtended maximum horizontal and vertical visual angles of 1.5 degrees and 0.4 degrees, respectively. Word-stems subtended maximum horizontal and vertical visual angles of 0.5 degrees and 0.4 degrees. The presentation of study items was paced by the experimenter. Each study item was presented at the centre of the screen, and remained on screen until the subject gave a

response (see below). The screen was blanked after each response, and then the next item was displayed.

Each test phase trial began with the display of a cue at the centre of the screen, indicating the task for this trial (either a 'X' or a '#'). The 'X' character indicated a recognition trial. The '#' character indicated a cued recall trial, in which a stem would be presented. The task cue remained on screen for 2s, and was followed immediately by a fixation asterisk displayed at the same position. The asterisk remained on the screen for 1s. The screen was then blanked for 120ms, after which the stimulus was displayed for 300ms, centred on the position occupied by the fixation asterisk. The screen was then blanked for 1.7s, after which a question mark was displayed to indicate that a response was now required (see below). After a 2.5s interval to permit a response to be made, the task cue for the next trial was displayed.

8.3.3 Procedure

Once the recording cap had been applied, subjects were seated in front of the stimulus presentation monitor. They were informed that the experiment involved a study phase and a test phase. In the study phase, a number of words would be presented. The study task required the generation of a sentence containing each presented item. The experimenter listened to the subject speaking the sentence, and then initiated the display of the next item following each response. If the subject was unable to form a sentence within approximately 10s, the next item was displayed. The duration of the study phase averaged about 20 minutes. On completion of the study phase, subjects were given a two minute rest.

At test, subjects were informed that they would see a list containing 360 items, of which half would be word-stems and the remainder whole words. Subjects were further informed that of each type of item, half corresponded to items which had been studied. They were also informed that a cue would be presented at the beginning of each trial to indicate the class of stimulus (word or stem) that would be presented, and thus the task for that trial. For recognition memory, the instructions

were to judge whether or not a word had been studied previously. For cued recall, the instructions were to attempt to recall a studied item with the aid of the stem. On both recognition and cued recall trials, subjects were instructed to withhold their response until the appearance on the monitor of a question mark, presented 2s after stimulus onset.

On each task, the required response involved indicating, using buttons placed on the desk in front of the subject, whether or not the stimulus corresponded to a studied item. For recognition memory, a specified button was to be pressed if the stimulus word had been studied ('old button'). Another button was to be pressed if the stimulus was not a studied item ('new button'). For cued recall, if the subject was able to complete a stem with a studied item, then the old button was to be pressed. If the stem could not be completed with a studied item within the required time (i.e. prior to the onset of the response cue, '?') then the new button should be pressed. The particular button used for each type of response, and therefore the hand used to indicate the response, was counterbalanced across subjects. The average duration of the test phase was approximately 1 hour. Subjects were given a short rest break every 90 trials.

To minimise EEG artefact, subjects were instructed to remain as relaxed and as still as possible during each trial. They were further instructed to refrain from blinking during the period beginning with the display of the fixation asterisk and ending with the display of the question mark.

8.3.4 ERP Recording

EEG was recorded from 27 tin electrodes embedded in an elasticated cap (Electro-cap). The location of these sites on the scalp is depicted in figure 4.2.

EEG was recorded with respect to a left mastoid reference. A separate right mastoid channel was also recorded, and used to re-reference the EEG to a linked (average) mastoid reference. EOG was recorded bipolarly using electrodes placed just above

the supra-orbital ridge of the right eye, and adjacent to the outer canthus of the left eye. All channels were amplified with a bandpass of 0.03 to 35Hz (3dB points) and sampled on-line at a rate of 6ms per point. The recording epoch was 1536ms, beginning 102ms prior to stimulus onset. The duration of recorded post-stimulus EEG was therefore 1434ms. The drift-from-baseline averaging criterion employed in this study was 60uv. For each subject, ERPs were formed for conditions in which there were at least 16 artefact-free trials available.

8.4 Results

8.4.1 Behavioural Data

The behavioural data are summarised in table 8.1. As for the presentation of behavioural data from experiments 1, 2 and 3, table 8.1 shows separately the data from all (19) subjects who completed the experiment, and the subset of 16 subjects who contributed ERP data. A similar pattern of performance is evident in each group. The analyses of behavioural data which are reported below used the data from the group of 19 subjects (an identical pattern of results was obtained in the analogous analyses of data from the 16 subject group).

For cued recall, an average of 42.5% of stems belonging to studied items were correctly endorsed as such (Cued Recall hit rate). Of the stems which belonged to unstudied items, 17.0% were incorrectly judged as belonging to studied items (Cued Recall false alarm rate). The mean proportion of correctly identified old items (hits) on the recognition memory task was 87.9%. The mean proportion of new words incorrectly endorsed as old (false alarms) was 3.9%.

The cued recall and recognition memory hit rates were each corrected for guessing by subtracting the respective false alarm rates. In each case, the corrected rates were significantly greater than zero ($t(18) = 10.20$, $p < 0.001$, and $t(18) = 39.46$, $p < 0.001$, for recognition and cued recall respectively). The corrected recognition hit

rate was also significantly larger than the corrected cued recall hit rate ($t(35) = 18.28$, $p < 0.001$). Finally, the cued recall false alarm rate was significantly larger than that for the recognition task ($t(18) = 4.30$, $p < 0.001$).

8.4.2 Analysis of Reaction Times

Table 8.2 shows the mean reaction times from the 16 subjects who contributed to ERPs. Inspection of table 8.2 shows that the reaction times for responses in all conditions were some few hundred milliseconds larger than 2s, which is to be expected given the task-instruction to refrain from responding until the response cue was displayed at 2s post-stimulus. The data shown in table 8.2 were analysed by repeated measures ANOVA employing the factors of task and condition. The ANOVA gave rise to a significant main effect of task [$F(1,18) = 22.59$, $p < 0.001$]. This effect occurred because reaction times in the hit and false alarm conditions on the cued recall task were generally slower than those for the recognition task.

8.4.3 Event-Related Potentials: Recognition Memory

Separate within task comparisons were initially made to establish that ERPs differed reliably for the recognition memory and the cued recall tasks. In the first comparison, ERPs elicited by correctly identified 'old' words (*hit* ERPs) were contrasted with ERPs elicited by correctly rejected 'new' words (*correct rejection* ERPs) (see figure 8.1). This comparison was performed upon ERP data from 13 of the 25 electrode sites (figure 8.1 shows data from all 25 sites, figure 8.2 shows data from just the 13 selected sites). These 13 sites corresponded to the montage used in the previous cued recall and stem completion studies (experiments 1-3), and also encompassed electrode sites used in a number of previous studies of recognition memory (e.g. Wilding and Rugg, 1996). These 13 sites were chosen so as to contrast directly the ERP effects obtained in the present experiment with the findings of these previous studies. Data from the remaining sites are however included in the topographical analyses, which are reported below.

Figure 8.2 shows the grand average hit and correct rejection ERPs at the three midline sites and 10 of the lateral sites. The mean number of trials used to form these ERPs was 67.4 (range 51-85) and 67.9 (54-82), for hits and correct rejections respectively. As expected, relative to correct rejection ERPs, hit ERPs exhibit a positivity which is larger and longer lasting over posterior left than right hemisphere sites. This parietally distributed positive shift appears to onset around 250ms, and is still evident, though diminished in magnitude, at the end of the recording epoch. In addition to the parietally distributed positivity, hit ERPs also show a more symmetrical frontally distributed positivity. The frontal and parietal positivities onset around the same time, but the frontal effect appears more sustained. A closer inspection of the figure shows that at the end of the recording epoch, the difference between these ERPs over the right hemisphere is largest at anterior sites. This is not the case at left hemisphere sites, where the positive shift extends more posteriorly.

Hit and correct rejection ERPs were analysed by ANOVA of mean amplitudes for selected latency regions, measured with respect to the mean amplitude of the 102ms pre-stimulus baseline period. These ANOVAs employed the factors of condition and site. ANOVAs of data from the midline sites (Fz, Cz and Pz) were conducted separately from those for the 10 lateral sites, which included the additional factor of hemisphere.

Exploratory ANOVAs of data from the midline sites over successive 100ms latency regions, beginning at 100-200ms, revealed a consistent pattern of enhanced positivity in hit ERPs over the 200-1434ms region. During this latency region, as is evident from figure 8.2, hit ERPs were more positive going than correct rejection ERPs to much the same extent at all three midline sites (i.e. no significant condition by site interactions were observed). At the lateral electrode sites, highly significant main effects of condition where also observed throughout the 200-1434ms latency region. Again, these were due to the enhanced positivity of hit ERPs. In addition to these main effects of condition, significant interactions involving the factors of condition and hemisphere were also observed. These interactions were strongest during the latter part of the recording epoch, from around 800ms onwards. Accordingly, the

results presented below employed mean amplitude measures from three more broad latency regions, covering the 500-800ms, 800-1100ms and 1100-1434ms periods. These latency regions are in general agreement with those chosen in previous ERP studies where old/new effects have been observed (see Chapter 3).

8.4.3.1 500-800ms

ANOVA of data from the midline sites gave rise to a significant main effect of condition [$F(1,15) = 25.70$, $p < 0.001$]. This effect was due to the enhanced positivity of hit ERPs, relative to correct rejection ERPs. ANOVAs of data from the lateral electrode sites also gave rise to a significant main effect of condition [$F(1,15) = 24.56$, $p < 0.001$]. Again, this was due to the enhanced positivity of hit ERPs.

8.4.3.2 800-1100ms

The ANOVA of data from the midline sites gave rise to a significant main effect of condition [$F(1,15) = 4.95$, $p < 0.05$], due to the enhanced positivity of hit ERPs. The ANOVA of data from the lateral sites also gave rise to a significant main effect of condition [$F(1,15) = 10.08$, $p < 0.01$], again due to the enhanced positivity of the hit ERPs. In addition, the condition by hemisphere interaction just failed of significance [$F(1,15) = 4.34$, $p = 0.055$]. The interaction was further investigated by a planned subsidiary ANOVA of data from the left and right parietal sites, which gave rise to a significant condition by site interaction [$F(1,15) = 5.12$, $p < 0.05$]. This interaction was due to the asymmetry of the positive shift in hit ERPs, which was only reliable at the left parietal site (Tukey HSD, $p < 0.01$).

8.4.3.3 1100-1434ms

The ANOVA of data from the midline sites did not give rise to a significant effect involving the factor of condition, though the main effect of condition approached significance [$F(1,15) = 4.17$, $p = 0.059$]. This was again due to the enhanced positivity of hit ERPs. The ANOVA of data from the lateral sites gave rise to a

significant main effect of condition [$F(1,15) = 9.69$, $p < 0.01$], and in addition significant interactions between condition and site [$F(2.2, 32.9) = 4.54$, $p < 0.025$] and condition, hemisphere and site [$F(2.6, 38.9) = 3.24$, $p < 0.05$]. The planned subsidiary ANOVA of data from the left and right parietal sites gave rise to a significant main effect of condition [$F(1,15) = 9.10$, $p < 0.01$], but the interaction between condition and site was not significant, and thus does not help to explicate the above three-way interaction.

As a means of further elucidating the significant three-way interaction noted above, two subsidiary ANOVAs, contrasting the hit and correct rejection ERPs at all 5 left and right hemisphere sites, were carried out. These ANOVAs both gave rise to significant main effects of condition (left: [$F(1,15) = 10.61$, $p = 0.005$]; right [$F(1,15) = 5.67$, $p < 0.05$]) and also significant interactions between condition and site (left: [$F(2.8, 41.6) = 3.05$, $p < 0.05$]; right [$F(2.2, 33.2) = 5.15$, $p < 0.01$]). Further analyses of these interactions showed that a reliable difference between the hit and correct rejection ERPs was only present at the right frontal electrode site (Tukey HSD, $p < 0.05$).

Finally, in light of the finding of a reliable difference at the right frontal site, and of previous findings of a right frontal old/new effect [e.g. Wilding and Rugg,], a direct test for the presence of a frontally distributed asymmetry during this latency region was carried out. This involved an ANOVA of data from the left and right frontal electrodes. The ANOVA gave rise to a significant main effect of condition [$F(1,15) = 14.67$, $p < 0.0025$], but the interaction between condition and site was not significant.

In summary, the above analyses have shown that hit ERPs are more positive going than correct rejection ERPs from around 200ms until the end of the recording epoch. From approximately 800-1100ms, this positive shift developed a reliable asymmetry, which favoured left posterior electrode sites. During the 1100-1434ms latency region, differences between these ERPs over the right hemisphere were largest at the frontal electrode site.

8.4.4 Event-Related Potentials: Cued Recall

For cued recall, ERPs elicited by stems correctly endorsed as belonging to studied items (*recalled* ERPs) were contrasted with ERPs elicited by stems correctly judged as belonging to unstudied items (*new completion* ERPs) (figure 8.3 shows data from all 25 electrode sites, figure 8.4 shows data from the 13 selected sites). The grand average recalled and new completion ERPs were comprised of a mean of 31.6 (range 20-58) and 54.4 (range 26-77) trials respectively. Differences between the ERPs from these two conditions take the form of a temporally restricted positive shift in recalled ERPs. This shift onsets around 800ms or so, and is largest at more posterior sites, where it exhibits an asymmetry which favours the left hemisphere. The effect diminishes over time, but is still present at the end of the recording epoch.

Exploratory ANOVAs of data from the midline and lateral sites over successive 100ms latency regions basically confirmed the impression gained from visual inspection of the waveforms shown in figure 8.4. In summary, differences between the recalled and new completion ERPs were restricted to the 800-1100ms latency region, and were largest, indeed only reliable, at the lateral electrode sites. Therefore, data from the entire 800-1100ms latency region were selected for further detailed analyses, as presented below. These analyses also retain consistency with the foregoing analyses of ERPs from the recognition memory task during the same latency region.

8.4.4.1 800-1100ms

The ANOVA of data from the midline sites did not give rise to a significant effect involving the factor of condition. The ANOVA of data from the lateral electrode sites gave rise to a significant condition by hemisphere interaction [$F(1,15) = 9.04$, $p < 0.01$]. The planned subsidiary ANOVA of data from the left and right parietal sites gave rise to a significant interaction between condition and site [$F(1,15) = 9.64$, $p <$

0.01], which occurred because the enhanced positivity of recalled ERPs was only reliable at the left parietal site (Tukey HSD, $p < 0.05$).

8.4.5 Topographical Analyses: Across Task Comparisons

In the following comparisons, differences in the scalp topography of the ERP effects are contrasted as a function of task. These topographic analyses were conducted upon subtraction waveforms from each electrode site that directly represented the recognition memory and cued recall ERP effects. The waveforms were created by subtracting correct rejection ERPs from hit ERPs (recognition effect) and by subtracting new completion ERPs from recalled ERPs (cued recall effect). The data were subjected to ANOVA after they had been rescaled (see chapter 4) to remove the confounding influence of across-region and across-task differences in amplitude on the scalp distributions of each ERP effect.

As demonstrated by McCarthy and Wood (1985), the non-additive effects of changes in generator strength mean that in the absence of such rescaling, a significant interaction between, say, task and electrode site, cannot be unambiguously interpreted as evidence of a task-related difference in scalp distribution. Such evidence is an essential prerequisite for the conclusion that the neural generators of two ERP effects are not identical. The question of whether such an inequality holds for the ERP effects associated with recognition memory and cued recall is the primary concern of the present study.

8.4.5.1 800-1100ms

The contrast between the ERP effects from each task was carried out on the data from the 800-1100ms latency region, since this was the only latency region in which both effects were reliably present, as indicated by the above analyses of raw ERP data. Figure 8.5 shows topographic maps of the ERP effects from the recognition and cued recall tasks during the 800-1100ms latency region. At posterior sites, the distribution of each effect is similar, showing a clear asymmetry favouring the left

hemisphere. And of the two, the recognition memory effect shows the more marked asymmetry. The recognition memory effect also extends more anteriorly than the cued recall effect, which is absent at the lateral anterior sites. However, an initial global ANOVA of these data employing the factors of task and electrode site did not give rise to a significant interaction between these factors. This indicates that the distribution of the two effects does not differ reliably during this latency region.

8.4.6 Topographical Analyses: The Recognition Memory ERP Effect

As is evident from figure 8.1, the distribution of the differences between the hit and correct rejection ERPs from the recognition task appears to change over time. This change in the distribution of the recognition memory ERP effect is better depicted in figure 8.6, which shows topographical maps of the effect during the 500-800ms, 800-1100ms and 1100-1434ms latency regions. These maps were created using a spherical spline interpolation algorithm, used to interpolate the magnitude of the effects over the entire surface of the scalp based on the 25 data points from each electrode site (Perrin et al., 1987; 1989). As is evident from the spline maps for each latency region, the recognition effect exhibits an asymmetry favouring posterior left hemisphere sites. But during the 1100-1434ms latency region this posterior asymmetry is less evident, while a more frontally distributed effect with the opposite asymmetry has developed.

An initial global ANOVA of these data employed the factors of epoch (500-800ms, 800-1100ms and 1100-1434ms) and electrode site. The ANOVA gave rise to a significant interaction between these factors [$F(4.0, 59.8) = 2.82$, $p < 0.05$], indicating that, as suggested by figure 8.6, the topography of the recognition memory ERP effect changes over time. In the following analyses, subsidiary ANOVAs were conducted to elucidate this interaction. Initially, pairwise subsidiary ANOVAs were conducted which contrasted the effect at all electrode sites, during the a) 500-800ms vs. 800-110ms, b) 500-800ms vs. 1100-1434ms and c) 800-1100ms vs. 1100-1434ms latency regions. Significant epoch by site interactions were obtained only in the latter two cases (500-800ms vs 1100-1434ms: [$F(3.1, 46.6) =$

2.83, $p < 0.05$]; 800-1100ms vs 1100-1434ms: [$F(4.1, 62.2) = 3.51$, $p < 0.025$]). A further subsidiary ANOVA was then conducted on data from selected electrode sites, contrasted as a function of the 500-800ms vs. 1100-1434ms epochs. The sites chosen were the lateral anterior and posterior electrodes, at which the parietally and frontally distributed old/new effects have been found to be most prominent (e.g. Wilding and Rugg, 1996). These ANOVAs were used to specifically assess changes in the symmetry and anterior-posterior distribution of the ERP effects during each epoch. Each ANOVA employed the factors of epoch, chain (anterior vs. posterior), hemisphere, and site. Analogous ANOVAs of the 800-1100ms vs. 1100-1434ms latency regions did not reveal any additional information regarding changes in the distribution of the effect, so they are not included here.

8.4.6.1 500-800ms vs. 1100-1434ms

The ANOVA contrasting the distribution of the recognition effect during these latency regions gave rise to a significant interaction between epoch and site [$F(1.3, 18.8) = 8.28$, $p < 0.0075$], and also a significant interaction between epoch, hemisphere and site [$F(1.7, 25.4) = 7.56$, $p < 0.005$]. To elucidate the interactions, subsidiary ANOVAs were carried out which contrasted the distribution of the effect at the selected sites during each individual latency region. During the 500-800ms latency region, the ANOVA gave rise to a marginally significant chain by hemisphere interaction [$F(1,15) = 4.28$, $p = 0.056$], reflecting the posterior asymmetry (left greater than right) of the effect. During the 1100-1434ms latency region, the ANOVA gave rise to significant interactions between chain and hemisphere [$F(1,15) = 6.55$, $p < 0.025$], and also chain and site [$F(1.9, 29.2) = 5.26$, $p < 0.025$]. The chain by hemisphere interaction arose because the effect is more marked at right anterior than posterior sites, whereas at the left hemisphere sites there is no such anterior-posterior gradient. Thus, as a function of the two epochs employed, the initial posterior hemispheric asymmetry changes to a later anterior-posterior gradation which is present only at right hemisphere sites.

8.4.7 Onset Latency Analyses

Finally, estimates of the onset latency of the ERP effects for each task were determined by computing a series of point-by-point t-tests on the subtraction waveforms for each electrode site. As in experiment 1, onset latency was defined as the latency from which 15 or more consecutive points differed significantly from zero (at $p < 0.05$). The analyses indicated that the recognition memory effect first onset at 138ms at the lateral anterior left hemisphere LF and F7 electrodes. In contrast, the cued recall ERP effect first onset at 1014ms at the left parietal electrode site. The onset latency of the recognition memory effect at the left parietal site was 346ms.

8.5 Discussion

Discrimination of old and new items on both tasks was reliably above chance. However, the behavioural data clearly show the difficulty of the cued recall task, relative to the recognition task. For cued recall, the mean hit minus false alarm rate was 25.5%. This proportion indicates how often subjects were able to discriminate stems which belonged to studied as opposed to unstudied items, taking into account the contribution of guessing. For recognition memory, the mean hit minus false alarm rate was significantly greater, at 84%. Furthermore, the mean false alarm rate for cued recall (i.e. incorrectly endorsing the stem of an unstudied item as belonging to a studied item) was significantly larger (17%) than that for the recognition task (3.9%). In conjunction, these findings indicate a disparity in the difficulty of each task which is not unexpected, given the numerous previous findings which have shown that under similar conditions, recognition memory performance is typically better than cued recall (e.g. see Brown, 1975).

For recognition memory, ERPs evoked by correctly recognised old items (hit ERPs) were more positive-going than those evoked by correctly rejected new items (correct rejection ERPs). This effect onset first at anterior left hemisphere electrodes, at

138ms. This positive shift exhibited a left parietally distributed maximum during the 500-1100ms latency region (see figure 8.6a,b). Late in the recording epoch, from 1100ms onwards, this left parietal positivity diminished in magnitude, while in contrast a more sustained positivity was still present at frontal sites. Consistent with this, the topographical analyses showed that the recognition memory effect changed its distribution over time. Initially the effect exhibited a left greater than right parietally distributed asymmetry. The parietal effect was still present, though diminished in magnitude, at the end of the recording epoch. This had the effect of producing a diffuse positive shift over all anteror and posterior left hemisphere sites during the latter part of the recording epoch, while in contrast, at right hemisphere sites the effect was more restricted to the anterior sites (see figure 8.6c). These differences in the distribution of the effect over time are consistent with the notion that the recognition memory effect is composed of independent left parietal and right frontal components (Wilding and Rugg, 1996).

For cued recall, ERPs evoked by stems correctly endorsed as belonging to studied items (recalled ERPs) also exhibited an enhanced positivity, relative to ERPs evoked by stems of unstudied items correctly endorsed as such (new completion ERPs). In contrast to the recognition memory ERP effect, this cued recall ERP effect onset at 1014ms at the left parietal electrode site. This effect was found to be statistically reliable during the 800-1100ms latency region, and to exhibit a marked asymmetrical distribution which was maximal at the left and right parietal sites (see figure 8.5b). The distribution of the cued recall ERP effect was essentially identical to that of the recognition memory effect during this latency region.

8.5.1 Functional Interpretations of the ERP effects

8.5.1.1 Recognition Memory

As discussed in Chapter 3, the recognition memory ERP old/new effect has been fractionated into two components which appear to reflect the contribution of functionally and neuroanatomically distinct processes to recollection (i.e. the explicit

retrieval of information processed during a specific prior episode). The more commonly observed left parietal old/new effect has been linked to retrieval processes associated with recollection in a number of studies. Evidence for this conclusion will not be presented again here as it is dealt with fully in chapter 3. In light of this previous work, it seems reasonable to interpret the present finding of a left parietally distributed positivity for the recognition memory effect, in terms of the recollection of the prior occurrence of items at study.

As first reported by Wilding and Rugg (1996), a right frontal old/new effect can also be observed on modified tests of recognition memory involving source judgements (i.e. tests of memory for particular attributes of study episodes). Again, evidence for this was presented in detail in chapter 3. For example, in Wilding and Rugg's study, source judgements involved discriminating, for all items deemed to be old, the gender of the voice in which the item was presented auditorially at study. Relative to correct rejection ERPs, Wilding and Rugg found that ERPs evoked by correctly recognised old items exhibited a positive shift with a right frontal distribution which could be dissociated both temporally and topographically from the left parietal old/new effect which was also observed for ERPs in these conditions. The right frontal effect was reliably larger for items attracting correct than incorrect source judgements (as was the parietal old/new effect). Wilding and Rugg suggested a link between the frontal effect and processes supporting accurate source judgements. In particular, those processes concerned with the post-retrieval manipulation of episodic information.

Wilding and Rugg (1996) used the notion of 'working-with-memory' processes (Moscovitch, 1992; 1994) to develop a more specific functional account of the processes reflected by the right frontal effect. Using Moscovitch's framework, Wilding and Rugg suggested that the frontal effect may reflect post-retrieval integrative functions which act to cohere, or organise, 'disparate' retrieved fragments of a prior episode, to form an explicit representation of the episode. However, as noted in chapter 3, the frontal effect occurs on tasks which do not include an overt requirement to make source discriminations (Donaldson and Rugg, submitted,

experiment 2). However, this has only been reported on a test of associative recognition, which, it could be argued, may engage processes similar to those mediating source discriminations.

In the present study, the recognition memory ERP effect appeared to be composed of overlapping left parietally and right frontally distributed components. It is possible, therefore, that the frontal old/new effect observed here, and that first reported by Wilding and Rugg (1996), are manifestations of the same processes, since the time courses and scalp distributions of the two effects are similar. The present study is thus the first report of a right frontal effect in a standard test of item recognition. Possibly, this effect has not been observed in previous studies of item recognition because the duration of the recording epoch was not long enough to reliably distinguish an asymmetrical frontal old/new effect. In most previous ERP studies of recognition memory a recording epoch of around 1s has been used. Thus it is possible that more sustained frontally distributed effects, dissociating from the left parietal old/new effect, may be observed on standard tests of recognition memory, given only that a long enough recording epoch is employed.

If the functional account of the frontal effect given by Wilding and Rugg is to be retained, then the present results, and those of Donaldson and Rugg (submitted) require that it be modified. Although there would appear to be no demand in the present study for specific post-retrieval integrative operations on which source memory may be based, it is nonetheless possible that such processes may have operated in the present study, given the high level of performance in the present recognition task. In addition, the duration of the response preparation interval (2s) used here may also have facilitated post-retrieval processing of retrieved information, since subjects were not under a time pressure to respond as quickly as possible, as is often the case in ERP studies of recognition memory (e.g. Rugg and Doyle, 1992). Moreover, the response methodology used in the present experiment may even have necessitated that subjects hold in mind response-related information until the display of the response cue at 2s post-stimulus. The frontal effect may therefore reflect the occurrence of integrative processing upon retrieval products, but

this processing need not be engaged in a strategic manner in accord with specific task requirements. The effect may thus reflect a more general working memory (Baddeley, 1986; 1996), or working-with-memory, process which is not engaged specifically to 'solve' source tasks (see also the Discussion section of the following chapter 9, and the General Discussion, chapter 11).

8.5.1.2 Cued Recall

The topographic comparison of the cued recall and recognition ERP effects showed that each effect was similarly distributed over the scalp during the restricted latency region in which the cued recall ERP effect was statistically reliable (800-1100ms). The distribution of the cued recall ERP effect thus closely resembled that of the parietal old/new effect, though the onset latency of this effect was substantially delayed with respect to the onset of the recognition memory ERP effect. As noted above, the parietal old/new effect can be interpreted as reflecting some aspect of the retrieval processes which contribute to the recollection of studied items. A similar interpretation could thus be given to the left parietal effect observed for cued recall. Thus, the present study provides evidence for some similarity in the neural processing associated with explicit memory, despite the across task manipulation of retrieval cues.

However, the cued recall ERP effect lacked the more frontally distributed old/new effect present for recognition memory. This finding indicates that the neural processing accorded to items on each task was not entirely identical. It is possible to use the functional account of the frontal old/new effect described above, to give an account of why a frontal effect was not present for cued recall in the present study. Thus, post-retrieval processing of episodic information is associated with frontally distributed ERP effects which are more sustained than the left parietal effect which has been associated with explicit retrieval processes. In the case of the present cued recall task, it is possible that post-retrieval processing did not have sufficient time to develop, or did not occur at all. The reaction time data from this study provide some tentative support for this notion, in so far as they indicate that correct responses on

the recognition task were reliably faster, albeit only by some few hundred milliseconds, than correct responses on the cued recall task.

But perhaps the most critical feature of the present data in support of this notion is the finding that the onset latency of the parietal old/new effect for cued recall was substantially delayed with respect to that for recognition memory. If it is accepted that the parietal ERP effects for cued recall and recognition are functionally equivalent, and in addition reflect activity from the same neural generators (as parsimony dictates), then retrieval processing associated with explicit memory on cued recall was delayed compared to that for recognition memory. Given this delay, it is likely that further post-retrieval processing may have not reached the stage possible for retrieved information on the recognition task, before the end of the recording epoch.

The above ideas also have the merit of going some way towards accounting for the rather obvious differences between the cued recall ERP effects observed here, and in the initial study of cued recall (experiment 1). A number of across study differences are particularily conspicuous. First, the present cued recall ERP effect exhibited an hemispheric asymmetry which was absent in the effect observed in the initial study (and also absent in the ERP effect observed in experiment 3 for stem completion). Second, the present effect was more restricted to posterior sites than was the case previously, where the effect appeared largest over the more anterior electrode sites (see e.g. figure 5.1). Third, the onset latency of the cued recall effect observed here (1014ms) was some 700ms later in the present experiment than in the previous study of cued recall (around 300ms).

A number of factors may have contributed to bringing about these across study differences in the cued recall ERP effect. In the initial cued recall study, the requirement to give a completion for each item, and to further indicate whether or not the completion was studied, may have encouraged a more strict criterion for making an old judgement than was the case here. Subjects in the present study may have adopted a less strict response criterion, due to the present instructions, which

did not necessitate a verbal response on each trial. This may have encouraged subjects to guess when unsure of whether a stem could be completed by a studied item, thereby diluting the number of trials in recalled ERPs where recollection of the study item actually occurred.

Furthermore, in the present study, subjects were required to indicate only whether a given stem belonged to a studied item, though they were instructed to respond 'old' if and only if they had retrieved the studied item to which the stem belonged. It was therefore possible to make a correct 'old' judgement based solely upon recognition of the stem itself, without having recollected the study item at all. Given that subjects only had 2s in which to complete stems with studied items, it is possible that subjects could have adopted this less effortful strategy, involving a recognition judgement for the stem itself, which could presumably have been made on the basis of the familiarity of the stem, without recollecting the prior occurrence of the studied item to which the stem belongs.

In summary, it is possible that the differences in the cued recall ERP effects observed across the studies may reflect a number of factors. These include a) insufficient time to carry out an adequate search for studied items belonging to stems, b) the consequent dilution of any genuine retrieval-related ERP effect by correct responses made on the basis of guessing, a factor which may have been encouraged by the present task instructions, and c) the possibility that correct performance may be achieved even if the studied item is not retrieved, but instead the subject recognises the stem itself as being 'old'.

The underlying notion which ties together the above factors is that the degree of post-retrieval processing which was carried out on cued recall trials in the present experiment may have been substantially reduced or eliminated. In the absence of such processing, the associated cued recall ERP effect lacks the more sustained anteriorly distributed component which was so evident in the initial cued recall study. This account thus implies that there are multiple components to the cued recall ERP effect, as has been found to be the case for the recognition memory effect. In

addition to the left parietal effect observed in isolation in the present study, there may be an additional, more symmetrical and anteriorly distributed component, which was observed in the initial cued recall study. It is this anterior component which may reflect post-retrieval processing.

Critically, the cued recall ERP effect observed in experiment 1 may have reflected the summated activity of both hypothesised components. Hence each could not be reliably distinguished in that study. If correct, this account suggests that the cued recall ERP effect could be composed of a left parietal old/new effect, and possibly a more symmetrical, or even a right>left, frontal old/new effect. If so, it is therefore important to contrast ERP correlates of explicit memory on cued recall and recognition under conditions where the more frontally distributed ERP cued recall effect can be observed, so as to allow a contrast between this component and the frontal component observed for recognition memory.

To achieve this, the methodology used in the initial cued recall study can be employed, since, based on the findings of experiment 1, this methodology does give rise to a cued recall ERP effect with a more symmetrical and frontally maximal distribution. Thus, in the study presented in the following chapter 9, the methodology developed for experiment 1 is used again. This methodology, where responses are given verbally on each trial following a 3s response preparation period, can quite simply be adapted to suit the recognition task, while still equating all aspects of experimental procedure across each task. This will of course allow an interpretation of across task differences in ERP effects which is unconfounded by purely procedural differences, as in the present experiment.

8.6 Summary and Conclusions

The present study contrasted ERP correlates of memory-related processing on word stem cued recall and recognition memory. ERP effects associated with explicit memory on each task differed in terms of their onset latency, time course and scalp

topography. While each ERP effect shared a common parietally distributed asymmetrical distribution during the 800-1100ms latency region, an additional more sustained and frontally distributed effect differentiated the two ERP effects. This frontally asymmetrical effect, favouring the right hemisphere, was only present for recognition memory. There are substantial differences between the cued recall ERP effect observed here, and that observed in experiment 1. These were explained in terms of possible differences in the occurrence of post-retrieval processing across the two studies. Critically, post-retrieval processing occurring in experiment 1, but not in the present experiment, may be associated with a more frontally distributed ERP component, which was not observed in the present experiment. This possibility is investigated further in the next experiment.

Table 8.1 Behavioural Data for experiment 4. **Recognition Memory**: the percentage of correctly recognised old items (Hits), and the percentage of new items incorrectly judged as old (False Alarms). **Cued Recall**: the percentage of stems correctly (Hits) and incorrectly (False Alarms) endorsed as belonging to studied items. Standard deviations shown in brackets.

	HIT (%)	FALSE ALARM (%)
N=19		
RECOGNITION MEMORY	87.9 (7.7)	3.9 (3.9)
CUED RECALL	42.5 (13.5)	17.0 (15.0)
N=16		
RECOGNITION MEMORY	88.0 (8.4)	4.3 (4.2)
CUED RECALL	44.2 (13.9)	18.1 (15.9)

Table 8.2 Reaction time data for experiment 4. Means, in milliseconds (ms), for hit and false alarm responses on each task from all 19 subjects. Standard deviations are shown in brackets.

	HIT (ms)	FALSE ALARM (ms)
RECOGNITION MEMORY	2758.8 (135.2)	2485.6 (1125.3)
CUED RECALL	2918.2 (155.4)	2907.1 (743.1)

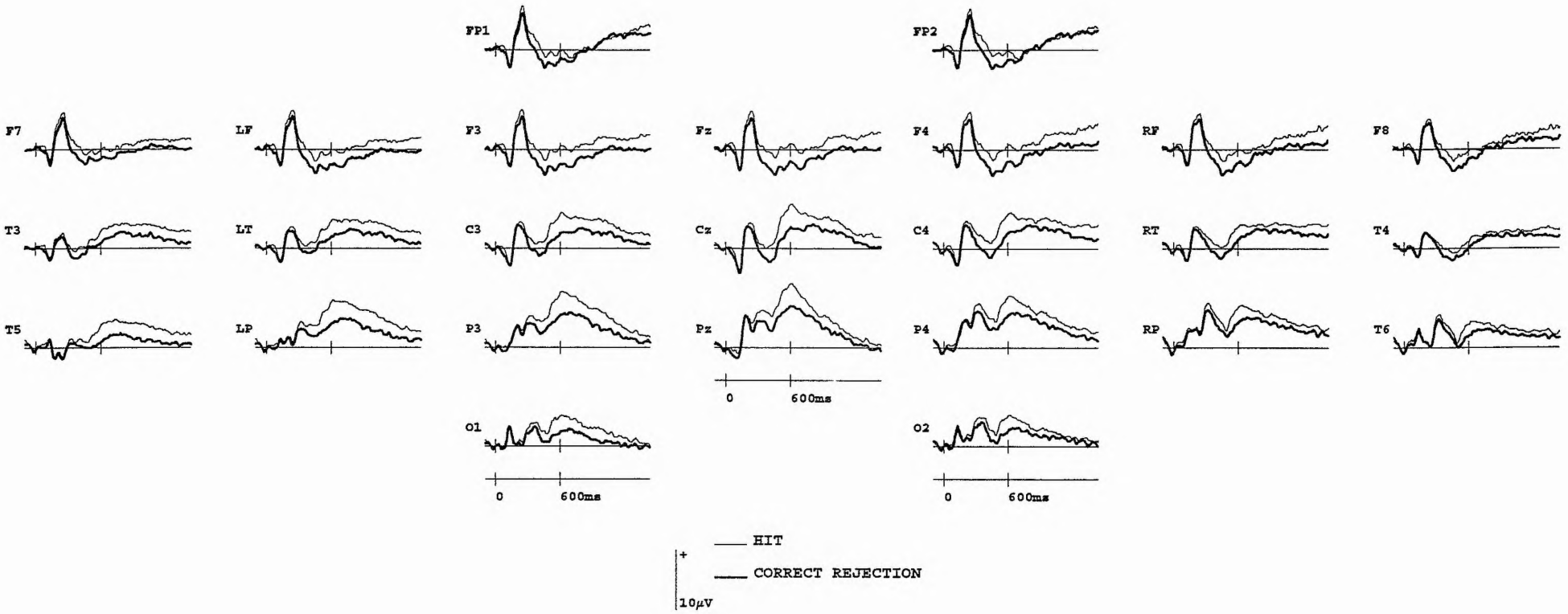


Figure 8.1 Grand average ERPs evoked by correctly recognised 'old' items (*hit* ERPs) and ERPs evoked by correctly rejected 'new' items (*correct rejection* ERPs), at all 25 electrode sites. See figure 4.1 legend for description of site labels.

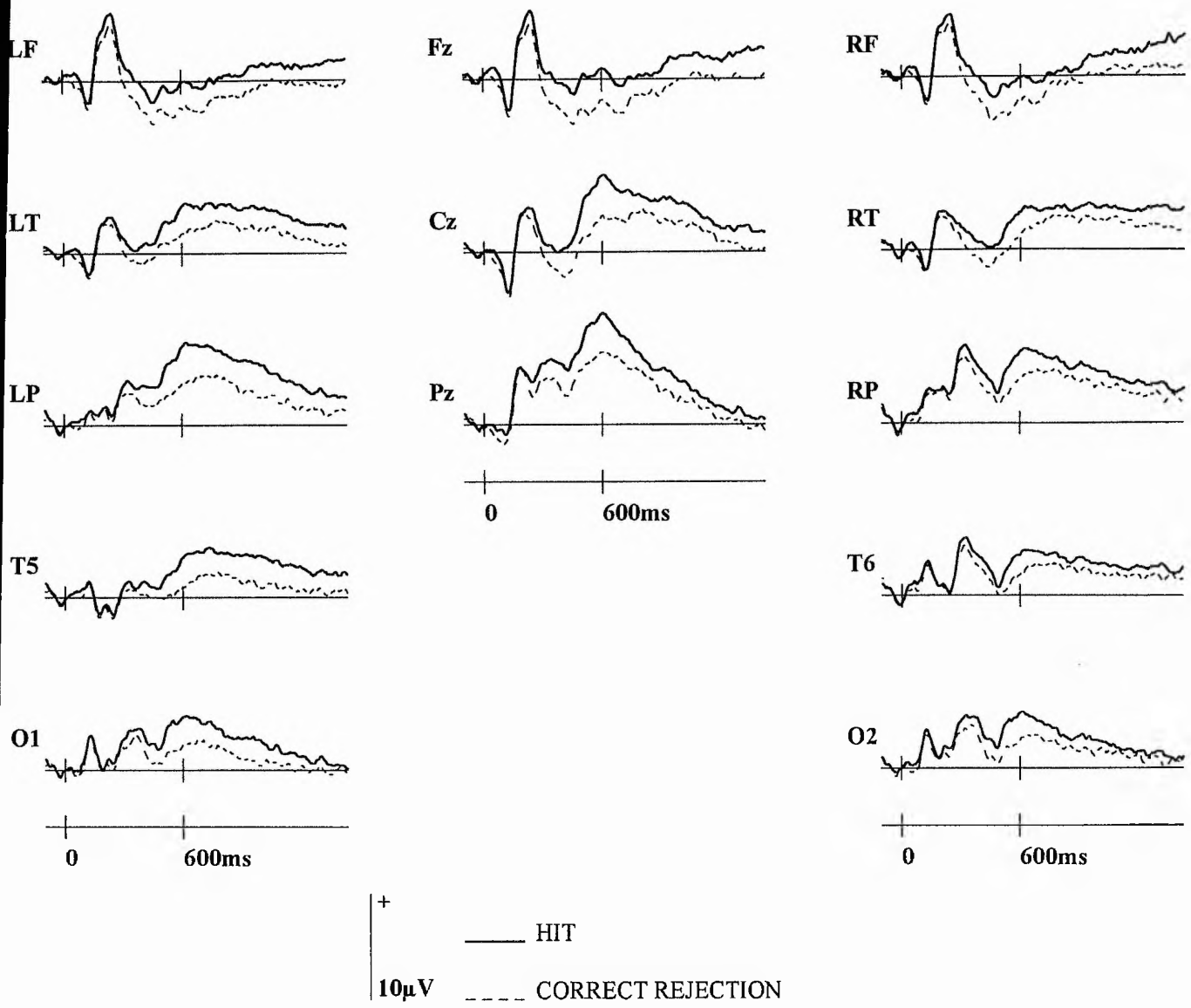


Figure 8.2 Grand average hit and correct rejection ERPs at the 13 sites of the 'standard electrode montage'. See figure 4.2 legend for description of site labels.

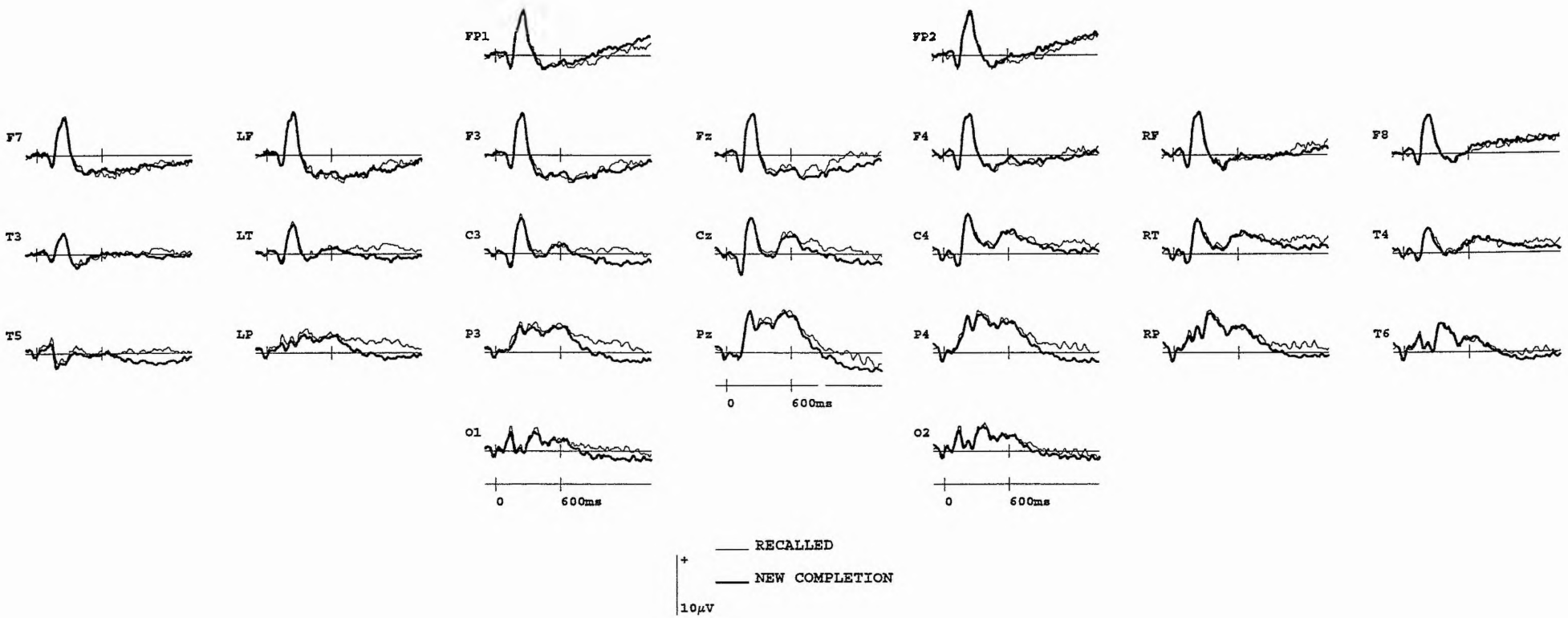


Figure 8.3 Grand average ERPs from all 25 electrode sites, evoked by stems correctly endorsed as belonging to studied items (*recalled* ERPs), along with ERPs evoked by stems correctly endorsed as belonging to unstudied items (*new completion* ERPs). Electrode sites as for figure 8.1.

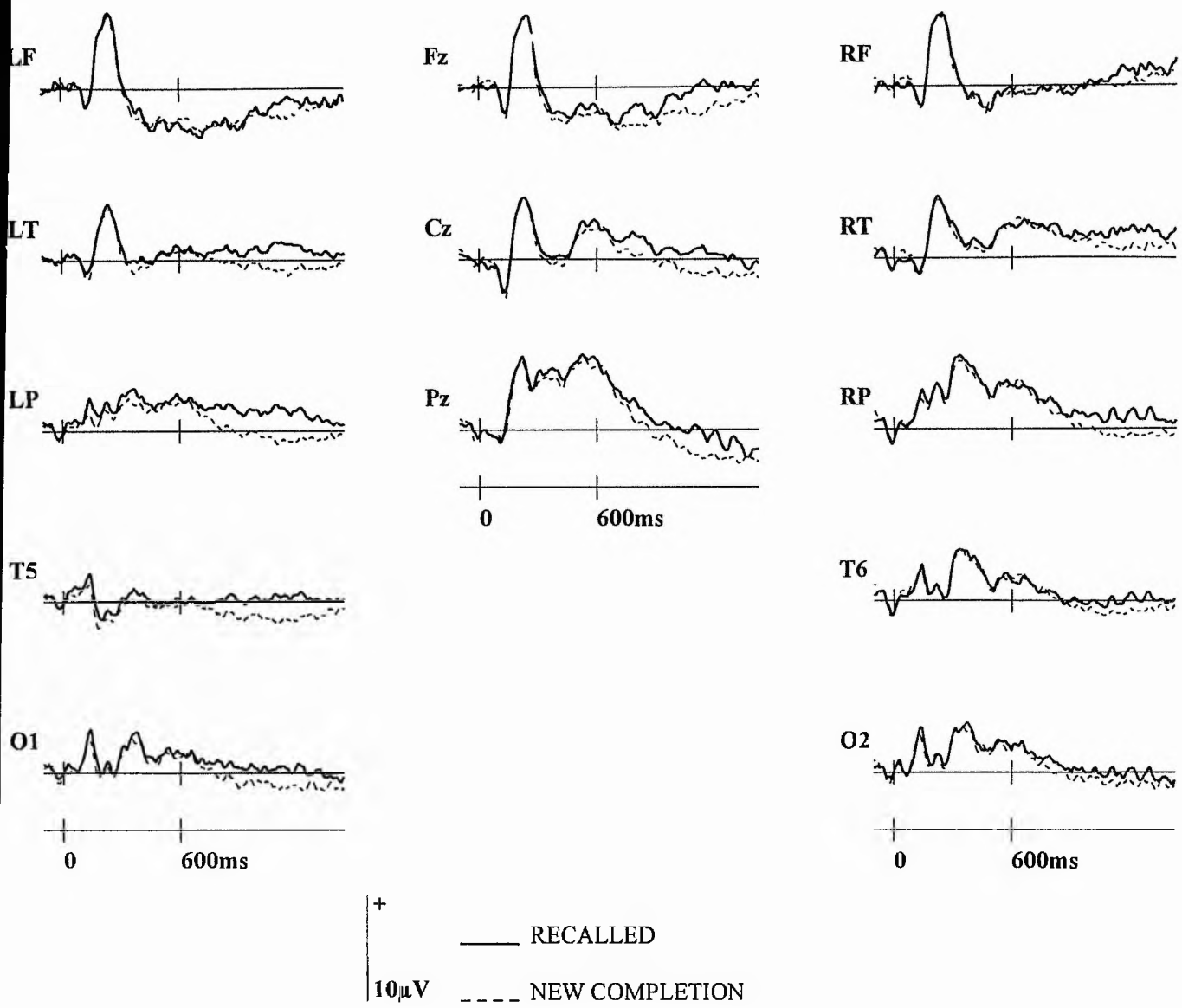


Figure 8.4 Grand average recalled and new completion ERPs. Electrode sites as for figure 8.2.

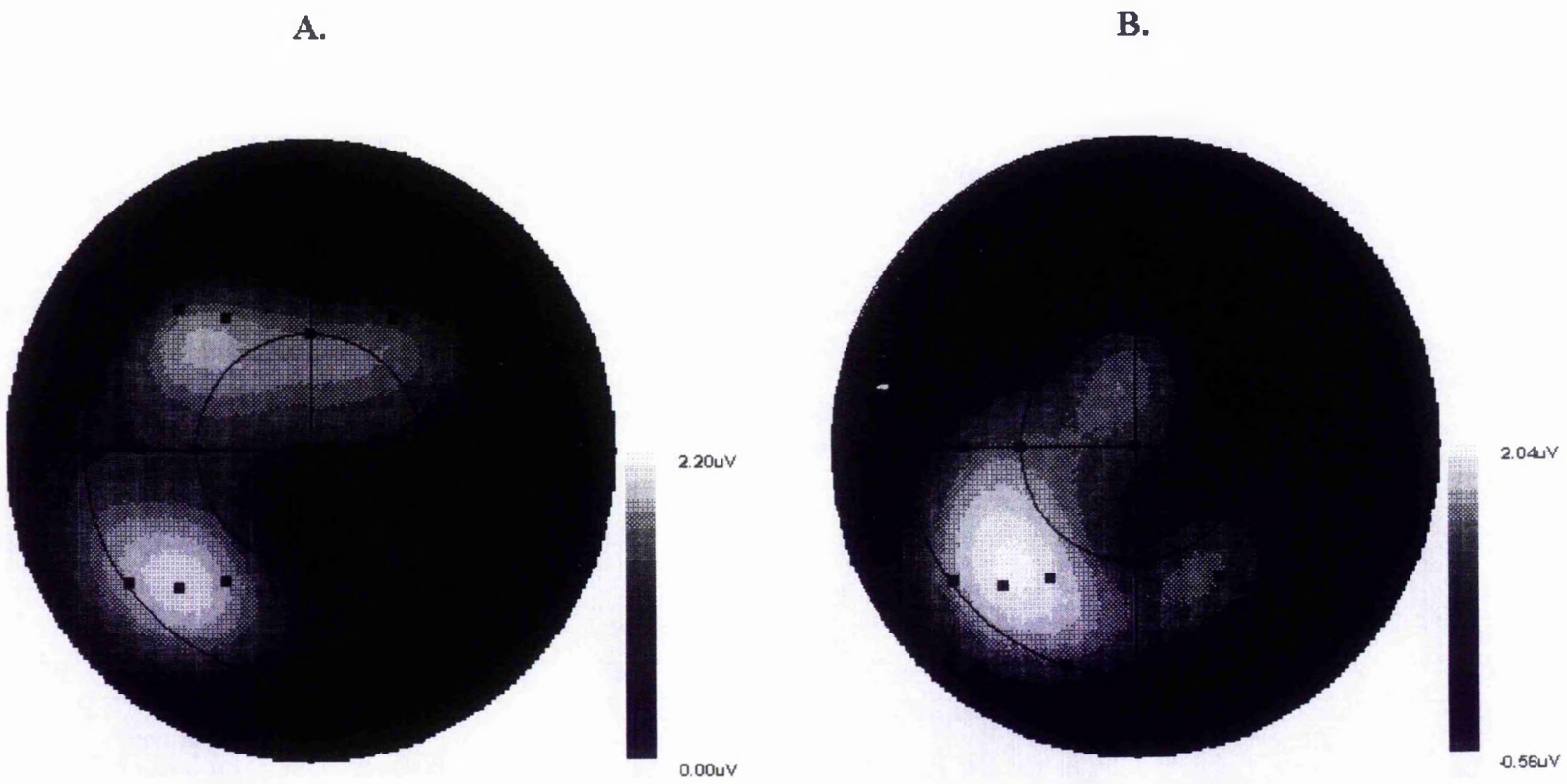


Figure 8.5 Topographic voltage maps contrasting the recognition memory and cued recall ERP effects. The figure shows the relative amplitude of the differences between ERPs from each task during the 800-100ms latency region, incorporating data from all 25 electrode sites. The scale bar to the right of each map indicates the mean maximum and minimum values of the magnitude of the old/new effect across all sites during the selected latency regions.

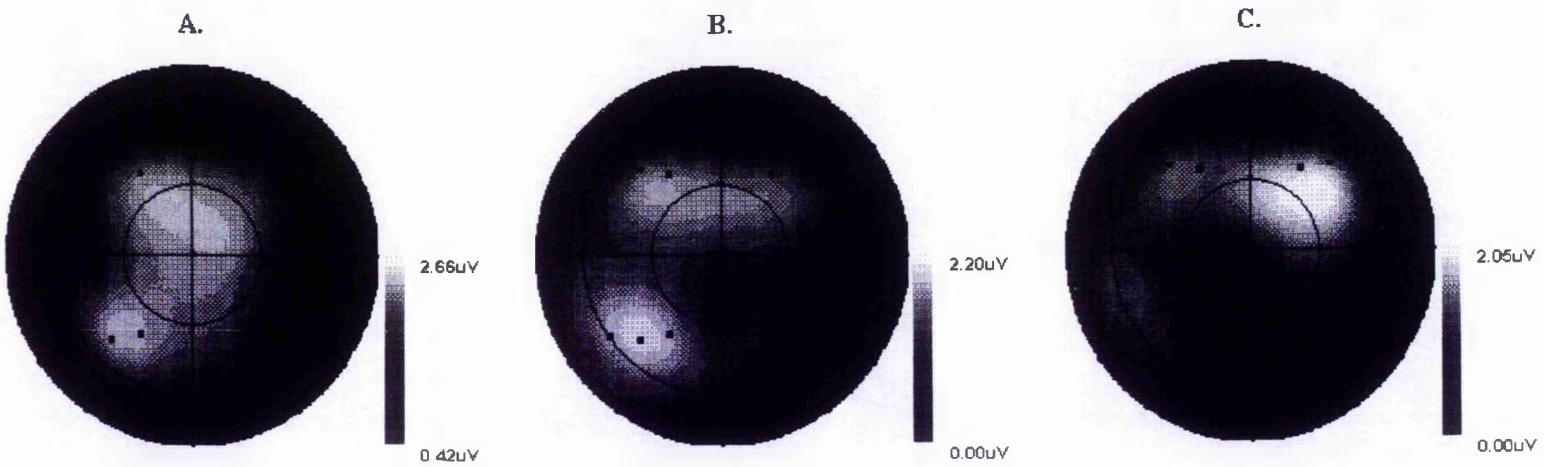


Figure 8.6 Topographic voltage maps for the recognition memory ERP effect, showing the change in the effects distribution over time. Scale bar as for figure 8.5

9.0 Event-Related Potential Correlates of Explicit Retrieval on Tests of Cued Recall and Recognition Memory (2)

9.1 Introduction

In the previous study (experiment 4), evidence was obtained which suggested that the recognition memory ERP effect was composed of two components, with, respectively, left parietal and right frontal maxima. In contrast, the observed cued recall ERP effect was topographically restricted to the more posterior electrode sites. At these sites, a reliable asymmetry, favouring the left hemisphere, was observed. This parietally maximal asymmetry was essentially identical to that observed for the recognition memory effect.

The parietally distributed effects observed for each task were interpreted as reflecting retrieval processes associated with the recollection of information from the episode in which items were presented at study. The frontal effect observed solely for the recognition task was interpreted in terms of post-retrieval processing, possibly involving frontal lobe structures, which act to integrate retrieved information into a coherent explicit representation of the study episode.

In the case of the previous experiment, no specific requirement for post-retrieval processing was made, other than that incurred by the necessity to wait for a period of 2s prior to responding on each trial. This requirement may possibly have been associated with the finding of a frontally distributed old/new effect on this otherwise 'standard' recognition memory task. If correct, this speculative account suggests that the frontal old/new effect may be observed on tasks in which even the most minimal form of post-retrieval processing is required. That is, the holding in mind of retreived information over the period of a retention interval.

This account of the frontal old/new effect implies that the absence of such an effect in the cued recall ERPs was because in that case post-retrieval processing did not occur very often, if at all. This may have been brought about by the use in the previous study of a 2s response preparation interval, which in the case of the cued recall task, may have been insufficient time to allow post-retrieval processing to proceed to an equivalent degree as was the case for the recognition task.

The cued recall ERP effect observed in the previous study differed substantially from that observed in the initial study of cued recall presented in chapter 5 (e.g. contrast figures 5.1 and 8.4). To explain these differences across tasks, I suggested that some aspects of the experimental procedure in the previous experiment may have contributed to the elimination of post-retrieval processing of information on cued recall trials. In turn, this lack of post-retrieval processing may account for the absence of the more symmetrical and anteriorly distributed cued recall ERP effect which was observed in the initial cued recall study.

The aim of the present study is to contrast ERP correlates of memory-related processing on the cued recall and recognition tasks, under conditions where post-retrieval processing can occur on each task. To achieve this, the methodology developed for the initial cued recall study (experiment 1) was employed. This involves the use of a verbal response on each cued recall trial. As for experiment 1, subjects were asked to give a completion for each stem, and also to indicate, by saying either 'old' or 'new', whether each completion was a studied or an unstudied item. As detailed below in the method section, a verbal response was also required on the recognition task. In this case subjects were asked, on each trial, to repeat the stimulus word, and then to say old or new to indicate their recognition decision.

Given that the conditions of the cued recall task in the present experiment closely match those for experiment 1, it would be reasonable to predict certain patterns of ERP effects which may be observed in this study. The ERP correlate of explicit memory identified in experiments 1 (and 3) differs in terms of scalp topography

from the ERP old/new effects observed for recognition memory. In the present study, ERP effects for each task are thus predicted to differ qualitatively in terms of their scalp topography. For recognition memory, ERPs evoked by recognised old items are predicted to show a positive shift with an asymmetrical, temporo-parietally maximal scalp topography, relative to ERPs elicited by correctly rejected 'new' items. Based on the findings for recognition memory from the previous experiment 4, a frontally distributed old/new effect may also be observed in the present study. Indeed, such an effect should be observed here given that the present study will also require subjects to wait during a response preparation interval before giving a response. By contrast, ERPs evoked by stems cueing the explicit retrieval of studied items are predicted to show a more sustained and symmetrically distributed positive-shift, relative to ERPs evoked by stems completed with unstudied items.

Finally, the present study employs the full 25 channel electrode montage used in the previous experiment 4, to gain a reasonably fine grained picture of the spatial distribution of ERP effects from each task. In addition, the present study employs a longer recording epoch than has hitherto been employed in any previous ERP study of recognition, and of course, cued recall. The recording epoch of approximately 2s will alone give new information concerning the ERP effects for each task. In particular, it will be of interest to see whether or not the cued recall ERP effect does develop an asymmetrical (right > left) distribution during the latter region of the recording epoch, as is observed with the right frontal old/new effect for recognition memory.

9.2 Method

9.2.1 Design Overview

The experiment employed a blocked design consisting of four identical study/test phases. In total, each subject studied 160 critical items, with 40 items presented at

each study phase. Memory for studied items was assessed using either a recognition task or a word-stem cued recall task.

9.2.2 Subjects

Subjects were 18 young adults, each paid £3.50 per hour. The data from two subjects were discarded because each failed to complete all four study/test blocks, and therefore did not provide sufficient trials to form ERPs in critical conditions. Of the remaining 16 subjects, 10 were female and all were right handed. Their mean age was 22yrs (range 17-28). All subjects were native English speakers, with normal or corrected-to-normal eyesight.

9.2.3 Stimuli

The stimuli were taken from the new set of experimental items, and consisted of a pool of 320 words. The first three letters, or stem, of each word was unique. The pool of 320 words was partitioned at random into two sets of 160 critical words. Half of the subjects studied one set of critical items, and the remaining subjects studied the other set. Each set of 160 critical items was divided into four 40 item study lists, with 2 buffer items at the beginning and the end of each list. Two different orderings of critical items in each study list were created to remove item order effects.

Each test list comprised 40 critical items, plus 40 'new' items drawn from the set of 160 items which were not studied. The presentation format of test items (as a word or a stem) was counterbalanced across two test lists. Thus, each study list had four corresponding test lists, each containing 40 words (20 studied), 40 stems (20 belonging to studied items) and 2 buffer items at the beginning of each list (one word and one stem).

Stimuli were presented at both study and test in upper case on a TV monitor (white on a black background). Word stimuli subtended maximum horizontal and vertical visual angles of 1.5 degrees and 0.4 degrees, respectively. Word-stems subtended

maximum horizontal and vertical visual angles of 0.5 degrees and 0.4 degrees. The presentation of study items was paced by the experimenter. Each study item was presented at the centre of the screen, and remained on screen until the subject gave a response (see below). The screen was blanked after each response, and then the next item was displayed.

Each test phase trial began with the display of a cue at the centre of the screen, indicating the task for this trial (either a 'X' or a '#'). The 'X' character indicated a recognition trial. The '#' character indicated a cued recall trial, in which a stem would be presented. The task cue remained on screen for 1s, and was followed immediately by a fixation asterisk displayed at the same position. The asterisk also remained on the screen for 1s. The screen was then blanked for 120ms, after which the stimulus was displayed for 300ms, centred on the position occupied by the fixation asterisk. The screen was then blanked for 2.7s, after which a question mark was displayed to indicate that a verbal response was now required (see below). After a 3s interval to permit a response to be made, the task cue for the next trial was displayed.

9.2.4 Procedure

Once the recording cap had been applied, subjects were seated in front of the stimulus presentation monitor. They were informed that their memory for words would be assessed in four study/test blocks, and that in each block 40 items would be presented for study. At study, subjects were instructed to generate a sentence containing each presented item, and then to say that sentence out loud. The experimenter listened to the sentence, and initiated the display of the next item following each response. If the subject was unable to form a sentence within approximately 10s, the next item was displayed. The duration of each study phase averaged about 4 minutes. On completion of each study phase, subjects were given a two minute rest.

In each test phase, subjects were informed that they would see a list containing 40 words (20 of which had been studied) and 40 stems (20 of which belonged to studied items), presented in a random order. They were also informed that a cue would be presented at the beginning of each trial to indicate the class of stimulus (word or stem) that would be presented, and thus the task for that trial. For recognition memory, the instructions were to judge whether or not a word had been studied previously. For cued recall, the instructions were to attempt to recall a studied item with the aid of the stem. If recall was impossible, the stem was to be completed with the first suitable word to come to mind. On both recognition and cued recall trials, subjects were instructed to withhold their response until the appearance on the monitor of a question mark. For recognition memory, the required response was to repeat the test word, and then to say 'old' if it had been studied, or to say 'new' if the word was new. For cued recall, the response requirement was to give a completion for the stem, followed by 'old' if the completion was a studied item, and 'new' if not. The duration of each test block was approximately 15 minutes. Subjects were given a short rest break halfway through each block.

To minimise EEG artefact, subjects were instructed to remain as relaxed and as still as possible during each trial. They were further instructed to refrain from blinking during the period beginning with the display of the fixation asterisk and ending with the display of the question mark.

9.2.5 ERP Recording

All aspects of EEG recording were identical to those given for the previous experiment 4, with the sole exception of the on-line sampling rate and duration of the recording epoch. In this study, the sampling rate was 8ms per point, and the duration of the recording epoch was 2048ms, beginning 104ms prior to stimulus onset. The duration of recorded post-stimulus EEG was therefore 1944ms. For each subject, ERPs were formed for conditions in which there were at least 16 artefact-free trials available.

9.3 Results

9.3.1 Behavioural Data

The behavioural data for all 16 subjects are summarised in table 9.1 [7]. For cued recall, an average of 44.5% of the stems belonging to studied items were correctly completed. 95% of these completions were retrieved explicitly, as evidenced by a correct recognition decision. The mean proportion of correctly identified old items (hits) on the recognition memory task was 93.3%.

The proportion of old stems associated with explicit retrieval, and the proportion of hits on the recognition task, were each corrected for guessing by subtracting the appropriate false alarm rate (the rate for cued recall was defined as the proportion of completions to stems of unstudied items which were falsely endorsed as old). In each case, the corrected rates were significantly greater than zero ($t(15) = 14.44$, $p < 0.001$, and $t(15) = 60.89$, $p < 0.001$, for cued recall and recognition respectively). In addition, the corrected recognition hit rate was significantly greater than the corrected rate of explicit retrieval for cued recall ($t(15) = 18.06$, $p < 0.001$).

9.3.2 Event-Related Potentials: Recognition Memory

As in the previous experiment 4, separate within task comparisons were initially made to establish that ERPs differed reliably for the recognition memory and the cued recall tasks. In the first comparison, ERPs elicited by correctly identified 'old' words (*hit* ERPs) were contrasted with ERPs elicited by correctly rejected 'new' words (*correct rejection* ERPs). This comparison was performed upon ERP data from the 13 (three midline and 10 lateral) sites of the standard montage depicted in figure 4.1 (figure 9.1 shows data from all 25 electrode sites, and figure 9.2 shows data from just the 13 selected sites). These 13 sites were chosen so as to contrast

[7] Behavioural data from all 18 subjects is not presented since two subjects did not complete the experiment.

directly the ERP effects obtained in the present experiment with the findings of the previous studies. Data from the remaining sites are included in the topographical analyses reported below.

Figure 9.2 shows the grand average hit and correct rejection ERPs at the three midline sites and 10 of the lateral sites. The mean number of trials used to form these ERPs was 60.5 (range 45-75) and 59.7 (38-77), for hits and correct rejections respectively. As expected, relative to correct rejection ERPs, hit ERPs exhibit a positivity which is larger and longer lasting over posterior left hemisphere sites. This positive shift appears to onset around 400ms and to offset at the left parietal site at around 1200ms. In addition to the parietally distributed positivity, hit ERPs also show a frontally distributed positivity (largest at the Fz and RF sites). This anterior positivity onsets with the parietal positivity but is more sustained over time. The extended recording epoch employed here thus permits a clear view of the apparent temporal and topographic dissociation between the parietally and frontally distributed components of the positive shift present in the hit ERPs.

Hit and correct rejection ERPs were analysed by ANOVA of mean amplitudes for selected latency regions, measured with respect to the mean amplitude of the 104ms pre-stimulus baseline period. These ANOVAs employed the factors of condition and site. ANOVAs of data from the midline sites (Fz, Cz and Pz) were conducted separately from those for the 10 lateral sites, which included the additional factor of hemisphere. In these, and in all other ANOVAs, F ratios associated with more than one degree of freedom were corrected by the Geisser-Greenhouse procedure. Where reported, post-hoc analyses used the Tukey HSD, or Newman-Keuls method (as appropriate), with a significance level of $p < 0.05$.

Initial exploratory ANOVAs of data from the midline and lateral sites over successive 100ms latency regions, beginning at 100-200ms, revealed a consistent pattern of results over the 400-1200ms region, wherein the parietally distributed positivity for hit ERPs is present. From 1200ms onwards, differences between hit and correct rejection ERPs shift to a more frontal distribution. Accordingly, the

results presented below employed mean amplitude measures for two broad latency regions, covering 400-1200ms and 1200-1944ms. These latency regions were chosen in preference to the regions utilised in the previous study (experiment 4), since, as noted above, the temporal information provided by the extended recording epoch emphasises the dissociation between the frontal and parietal effects. Employing these more broad latency regions thus capitalises on the temporal information provided by the present study. In addition, the 100ms exploratory ANOVAs showed that there was no change in the pattern of the recognition memory effect over the 500-800ms vs. 800-1100ms latency regions which were employed in the previous study.

9.3.2.1 400-1200ms

ANOVA of the data from the midline sites gave rise to a main effect of condition [$F(1,15) = 5.02$, $p < 0.05$]. This effect was due to the enhanced positivity of hit ERPs. ANOVA of data from the lateral sites gave a significant condition by hemisphere by site interaction [$F(2.1,31.8) = 5.26$, $p = 0.01$]. The principal difference contributing to this interaction was revealed by a planned subsidiary ANOVA of data for the hit and correct rejection ERPs from the left and right parietal sites alone, which gave rise to a significant condition by site interaction [$F(1,15) = 19.06$, $p < 0.001$]. This interaction occurred because the difference between hit and correct rejection ERPs was larger at the left than at the right parietal site.

9.3.2.2 1200-1944ms

ANOVA of data from the midline sites gave rise to a significant condition by site interaction [$F(1.3,20.0) = 9.24$, $p < 0.005$]. Post-hoc analyses showed that hit ERPs were more positive than correct rejection ERPs, but only at the Fz electrode. ANOVA of data from the lateral sites gave rise to no significant effects involving the factor of condition.

9.3.3 Event-Related Potentials: Cued Recall

For cued recall, ERPs elicited by stems completed with recognised studied items (*recalled* ERPs) were contrasted with ERPs elicited by stems completed with correctly rejected unstudied items (*new completion* ERPs) (figure 9.3 shows data from all 25 electrode sites, and figure 9.4 shows data from just the 13 selected sites). The grand average recalled and new completion ERPs were comprised of a mean of 27.5 (range 16-45) and 51.8 (range 28-69) trials respectively. Differences between the ERPs from these two conditions take the form of a positive shift in recalled ERPs. This shift has a widespread scalp distribution, onsets around 400ms and continues until the end of the recording epoch. The exploratory ANOVAs of data from the midline and lateral sites over successive 100ms latency regions revealed that the differences between recalled and new completion ERPs were consistent throughout the recording epoch from 400ms onwards. Therefore, to retain consistency with the foregoing analyses of ERPs from the recognition memory task, ANOVAs of mean amplitudes of the 400-1200ms and 1200-1944ms latency regions are presented below.

The ANOVAs of data from the midline and lateral sites during the 400-1200ms and 1200-1944ms latency regions each gave rise to main effects of condition (400-1200ms, midline [$F(1,15) = 22.23$, $p < 0.001$], lateral [$F(1,15) = 16.50$, $p = 0.001$]; 1200-1944ms, midline [$F(1,15) = 21.96$, $p < 0.001$], lateral [$F(1,15) = 27.70$, $p < 0.001$]). In each case, main effects were caused by the greater positivity of the ERPs elicited by recalled items.

9.3.4 Topographical Analyses

In the following comparisons, differences in the scalp topography of the ERP effects are contrasted, both within and across tasks. These topographic analyses were conducted upon subtraction waveforms from each electrode site. The waveforms were created by subtracting correct rejection ERPs from hit ERPs (recognition effect) and by subtracting new completion ERPs from recall ERPs (cued recall effect). The data were subjected to ANOVA after they had been rescaled.

Figures 9.5 and 9.6 show topographic maps of the ERP effects from the recognition and cued recall tasks respectively. Figure 9.5 clearly shows the shift in the distribution of the recognition effect from left posterior to frontal electrode sites over time. By contrast, figure 9.6 shows that the distribution of the cued recall effect remains more constant throughout the entire 400-1944ms latency region. A global ANOVA of these data employing the factors of epoch (400-1200ms vs. 1200-1944ms), task and electrode site, gave rise to a significant interaction between all three of these factors [$F(4.3,64.0) = 2.78$, $p < 0.05$], indicating that, as suggested by figures 9.5 and 9.6, the topography of the ERP memory effects varies according to task and epoch. In the following analyses, planned subsidiary ANOVAs were conducted to elucidate this interaction by contrasting the ERP effects across both epoch and task. These ANOVAs employed data solely from the lateral frontal and parietal sites, specifically to assess differences in the symmetry and anterior-posterior distribution of the ERP effects for each task.

9.3.4.1 Across Epoch

The ANOVA contrasting the distribution of the recognition effect at the selected sites employed the factor of epoch, with three additional factors of hemisphere, chain (anterior vs posterior) and site (inferior vs superior). The ANOVA gave rise to significant interactions between epoch and hemisphere [$F(1,15) = 9.29$, $p < 0.01$], and epoch and chain [$F(1,15) = 10.14$, $p < 0.01$]. The epoch by hemisphere interaction arose because the asymmetry of the recognition effect is present only during the early latency region. The epoch by chain interaction arose because the distribution of the recognition effect is more diffuse in the early region than in the later epoch, where it shows a marked anterior distribution.

The analogous ANOVA contrasting the distribution of the cued recall effect at the selected sites gave rise to a significant four-way interaction [$F(1,15) = 7.22$, $p < 0.025$]. The reasons for this interaction are not immediately evident. It appears to have arisen because of a shift over time towards a superior right frontal distribution, which can in fact be observed in figure 9.6b.

9.3.4.2 Across Task

The distribution of the two ERP effects were contrasted with one another in separate ANOVAs of data from the 400-1200ms and 1200-1944ms latency regions. The ANOVA of data from the earlier latency region gave rise to a significant interaction between the factors of task, hemisphere and chain [$F(1,15) = 4.75$, $p < 0.05$]. This interaction reflects the difference between the posterior and asymmetrically distributed recognition effect, and the more symmetrical and diffuse cued recall effect.

The ANOVA of data from the 1200-1944ms latency region yielded an interaction between the factors of task and chain which just failed to achieve significance [$F(1,15) = 4.30$, $p = 0.056$]. This effect was due to the markedly anterior distribution of the recognition effect, which contrasts with the more diffuse cued recall effect.

9.3.5 Onset Latency Analyses

Finally, estimates of the onset latency of the ERP effects for each task were determined by computing a series of point-by-point t-tests on the subtraction waveforms for each electrode site. As in the previous experiments, onset latency was defined as the latency from which 15 or more consecutive points differed significantly from zero (at $p < 0.05$). The analyses indicated that the cued recall ERP effect first onset at the F3 electrode at 512 msec post-stimulus. The recognition effect first onset at 456ms at the Fz and Cz electrodes.

9.4 Discussion

The performance measures showed that cued recall was the more difficult task, as judged by the difference between the hit rate in the recognition task, and the probability of explicit retrieval in the cued recall task (93.3% vs 42.9%). However,

the recognition hit rate did not exceed the proportion of correct completions to stems belonging to studied words which were subsequently recognised (95%). That is, subjects 'missed' correct completions about as often as they missed old items on the recognition task. Clearly, the difficulty in cued recall lay in retrieving studied items within the time provided, rather than in recognising retrieved items as previously studied.

For the recognition task, hit ERPs were more positive-going than correct rejection ERPs from around 400ms until the end of the recording epoch. This effect was composed of two topographically and temporally distinct components. During the 400-1200ms latency region, the effect had an asymmetrical, temporo-parietal scalp distribution (hereafter the 'parietal old/new effect'). From 1200ms onwards, the effect was confined to frontal electrodes and was maximal slightly to the right of the midline (hereafter the 'frontal old/new effect').

For the cued recall task, ERPs evoked by stems cueing explicit retrieval were more positive-going than ERPs evoked by stems completed with new items (hereafter the 'cued recall ERP effect'). The time course of this effect was similar to that of the frontal old/new effect observed for the recognition memory task. The cued recall effect was initially symmetrical, with a midline maximum. During the latter part of the recording epoch the effect became more pronounced over right superior anterior sites, though it was not confined to these anterior sites.

9.4.1 Functional Interpretations of the ERP Effects

9.4.1.1 Recognition Memory

The present finding of a parietally distributed old/new effect closely replicates the findings of the previous experiment 4, and also those of several previous studies of recognition memory (see chapter 3). Thus the requirement in the present study to withhold responses until 3s post-stimulus appears to have affected neither the time course nor the topography of this component of the old/new effect. As noted in the

discussion in the previous chapter 8, frontal old/new effects have not generally been observed in previous ERP studies of 'old/new' recognition memory. One possibility is that this effect has not been well observed previously because of the tendency to employ shorter recording epochs (typically < 1.5sec) than that employed here. The findings of the present study, and the previous study, thus reinforce the notion that it is important to record for sufficiently long enough in order to see whether or not a frontal old/new effect is present.

In light of the findings from the numerous previous ERP studies of recognition memory, it seems reasonable to suppose that the parietal old/new effect observed in the present study reflects the recollection of studied items. In addition, it is possible that the frontal old/new effect observed here, and that reported by Wilding and Rugg (1996), are manifestations of the same processes, since the time courses and scalp distributions (although not the magnitudes) of the two effects are similar. The relative weakness of the frontal effect in the present study, and in the previous study, may reflect the fact that subjects were not required to accompany their recognition decisions by contextual judgements, which may make particularly heavy demands upon frontal-lobe mediated, post-retrieval operations.

9.4.1.2 Cued Recall

The cued recall ERP effect observed in the present study replicates the findings of the initial cued recall study (experiment 1), where a sustained positive shift in ERPs evoked by stems cueing explicit retrieval, relative to ERPs evoked by stems completed with unstudied items, was also observed. The cued recall effect appears however to differ slightly across the two studies in its scalp distribution. In the present study the cued recall effect does not develop an anterior focus until later in the recording epoch. Whereas in the initial study of cued recall the effect was more clearly anterior in distribution practically from onset. The reason for this difference is not clear; it could reflect any one of a number of differences between the studies, such as the relative difficulty of cued recall in each study, the use of different encoding conditions, incidental versus intentional study instructions, etc. The present

finding of a late right anterior focus could not of course have occurred in experiment 1, since in that study the recording epoch was of an insufficient duration.

In any case, the aim of the present study was to allow a contrast between the more sustained and anteriorly distributed component of the cued recall ERP effect and the late frontal old/new effect. This aim was achieved, and the critical finding was that the distributions of the cued recall and recognition memory effects were quite different during both early and late periods of the recording epoch. The cued recall effect showed neither an early parietally distributed asymmetry, nor a later effect restricted to frontal electrode sites. The only evidence for similarity in the effects from each task took the form of a late right anterior focus for the cued recall ERP effect (see figure 9.6b). However, the distribution of the cued recall ERP effect was not restricted to the anterior electrodes, indicating that additional neural structures not engaged by the recognition task were engaged by cued recall. In spite of this difference, it is tempting to speculate that the right anterior focus of the cued recall effect may reflect activity from regions also contributing to the frontal old/new effect. In any case, the present findings clearly show that the brain regions engaged on each task are not completely identical.

I suggested in the discussion for experiment 1, that the cued recall ERP effect reflects explicit memory (recollection) for studied items. An alternative interpretation of the cued recall effect is that it is a correlate of changes in processes responsible for implicitly generating studied versus unstudied item completions for stems. This interpretation is, however, almost certainly incorrect, since the initial study showed that explicit memory was a necessary condition for the effect, which was not observed in ERPs for conditions where correct completion was unaccompanied by recognition. Thus, enhanced fluency of completion with a studied item, which may have occurred independently of explicit memory, is not sufficient in itself to modulate ERPs. The present findings are consistent with this interpretation.

9.4.1.3 Relating the ERP Effects observed on Each Task

A question which therefore arises is why ERP correlates of explicit memory should differ qualitatively at all, as a function of the task in which they are elicited. It would seem that there are at least two interesting possibilities. One already mentioned in the general discussion for chapter 7, is that the different effects reflect the fact that the brain activity associated with memory retrieval varies according to the cue (whole item vs. stem) that guides the retrieval operation. On the assumption that different retrieval cues could lead to the activation and recovery of different combinations of attributes of a prior event, the present findings fit well with this proposal.

A second possibility is that the ERP effects from each task differ in the nature of the post-retrieval processing engendered on each task, and not just in the retrieval processing activated by the different retrieval cues. In the discussion section for experiment 4 I suggested that the cued recall ERP effect may be a composite of a left parietal and a more frontally distribued component, as is the recognition memory ERP effect. This multiple component view of the cued recall ERP effect derives mainly from the across study comparison of cued recall ERP effects observed in experiments 1, 4 and the present study. In experiment 4 the cued recall ERP effect took the form of a parietally distributed, asymmetrical positive shift. This effect was interpreted as reflecting the retrieval processes associated with recollection which also manifest in the left parietal old/new effect, as observed, for example, on tests of recognition memory. In contrast to the findings of experiment 4, in the present study and in experiment 1, the cued recall ERP effect was much more sustained, and symmetrically distributed, with, in experiment 1, a clear anterior > posterior graded distribution.

As mentioned in the discussion for experiment 4, these differences in the distribution of the cued recall effect may have reflected the inability of subjects to engage in post-retrieval processing of episodic information on that task. This may have resulted from the more restricted time period for response preparation (2s), and also the nature of that tasks' instructions (for more detail see Discussion, chapter 8). Thus,

the more frontally distributed component of cued recall ERP effect may reflect post-retrieval processing of information, rather than retrieval per se. In the present study, a more frontally distributed cued recall ERP effect was observed once again, which allowed it to be contrasted with the frontal old/new effect observed for recognition memory. The results of this comparision showed that the distribution of the cued recall and recognition ERP effects were not identical, though right hemisphere anterior foci were observed in each case. Therefore, if the cued recall ERP effect is also to be associated with post-retrieval processing, it is the case that such processing, across tasks, may overlap in some critical respects.

Finally, there are other sources of evidence which show that frontally distributed old/new effects can differ in terms of their exact distribution over the scalp. Critically, the distribution of frontal old/new ERP effects has been observed to change according to the exact paradigm in which they are elicited. For example, a symmetrical frontally distributed effect has been observed on a test of recency judgements for previously presented word-pairs (Tendolkar and Rugg, submitted). In addition, in a study of source memory for internally generated and externally provided study items, correct source judgments were associated with frontal old/new effects with a reduced (though still significant) degree of asymmetry (Wilding and Rugg, submitted). The present finding of a weakly asymmetrical right frontal old/new effect for recognition memory also indicates that the *degree of hemispheric asymmetry* exhibited by frontal old/new effects is variable. The exact distribution of frontal old/new effects over the hemispheres may therefore depend to some extent on the nature of the post-retrieval processing demanded by the given task.

9.5 Summary and Conclusions

In summary, the findings from this study clearly demonstrate that the ERP effects associated with explicit memory retrieval share common features. Differences in the ERP effects from each were observed, possibly because of differences in the retrieval processing engaged by word-stem cues, as opposed to whole word copy

cues. It seems likely in any case that the cued recall effect, and the recognition memory effect, are each composed of multiple components, associated with both retrieval and post-retrieval processing, respectively. These components give rise to ERP signatures which partially overlap, both spatially and temporally. The overlap is perhaps more complete in the case of cued recall, due to a delay in the onset of retrieval processing, as indicated by the onset latency of the parietal component of the ERP observed in experiment 4. The more complete overlap of the components contributing to the cued recall effect makes it difficult to distinguish them from one another in the cued recall tasks implemented in this thesis so far.

In the final study of this thesis, the nature of the processes reflected by the cued recall ERP effect is investigated using a source memory paradigm. Thus, in the study which follows (chapter 10), the nature of the processing reflected by the cued recall ERP effect was investigated by requiring subjects to make source judgments on a word-stem cued recall task, whenever they thought that a completion belonged to the study list. Contrasting ERPs in conditions where source can/cannot be recollected, will show whether the nature of the processes underlying the cued recall ERP effect are associated with recollection. If the effect is modulated according to whether subjects can recollect source, then the link between the effect and processes associated with recollection will be more firmly established. The experiment will also show what happens to the cued recall ERP effect when post-retrieval processing is actually an overt feature of the cued recall task. It is possible that under such conditions, each hypothesised component of the cued recall ERP effect will be evident.

Table 9.1 Behavioural data for experiment 5. Shown separately for the cued recall and recognition tasks (standard deviations are shown in brackets). **Cued Recall**: column 1, correct completion rate (mean percentage of correctly completed stems of studied words); column 2, mean probability of explicit retrieval (i.e. recognising a correct completion); column 3, false alarm rate, defined as the mean percentage of completions with unstudied items which were falsely recognised. **Recognition Memory**: column 1, hit rate (mean percentage of recognised old items); column 3, false alarm rate (mean percentage of falsely recognised new items).

	Correct Completion Rate (%)	**Probability of Explicit Retrieval**	**False Alarm Rate (%)**
CUED RECALL	44.5 (9.6)	0.95 (0.09)	3.4 (4.3)

	Hit Rate (%)	--	**False Alarm Rate (%)**
RECOGNITION	93.3 (6.3)	--	2.2 (1.9)

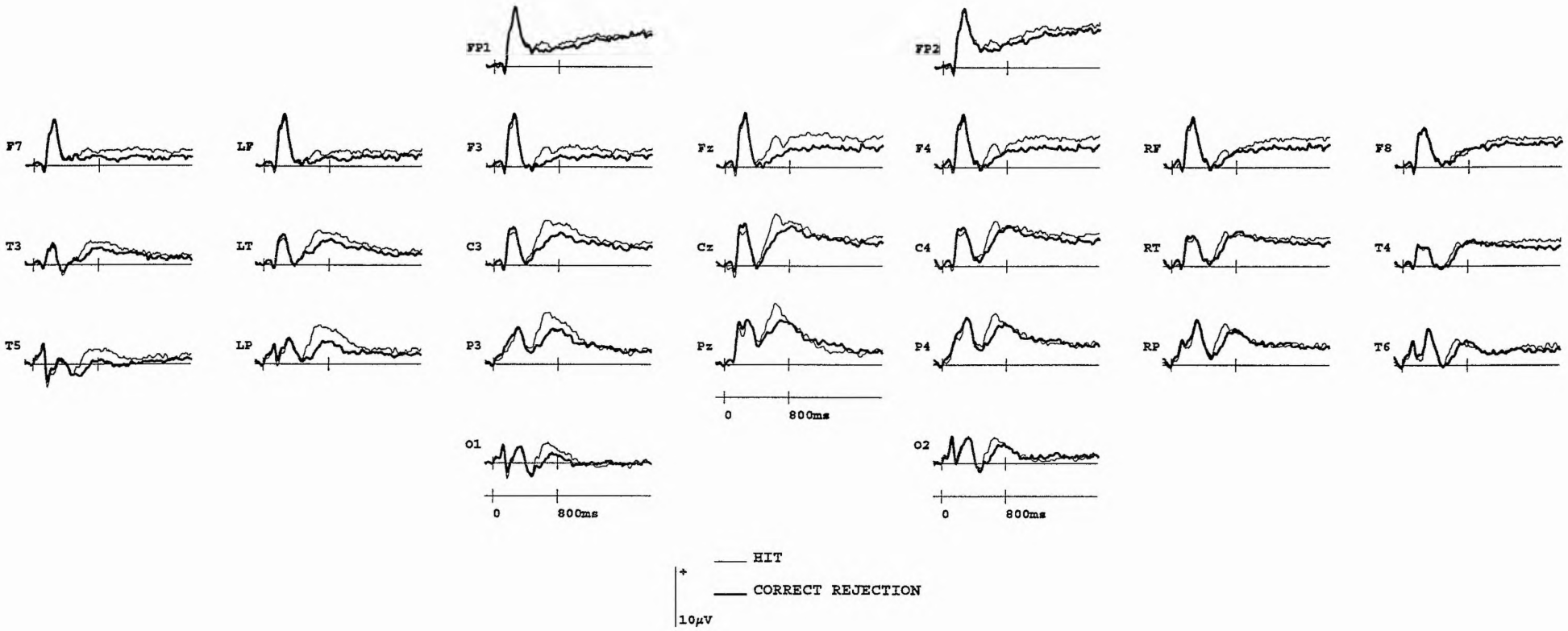


Figure 9.1 Grand average ERPs evoked by correctly recognised 'old' items (hit ERPs) and ERPs evoked by correctly rejected 'new' items (correct rejection ERPs), shown for all 25 electrode sites (see figure 4.1 legend for description of the site labels).

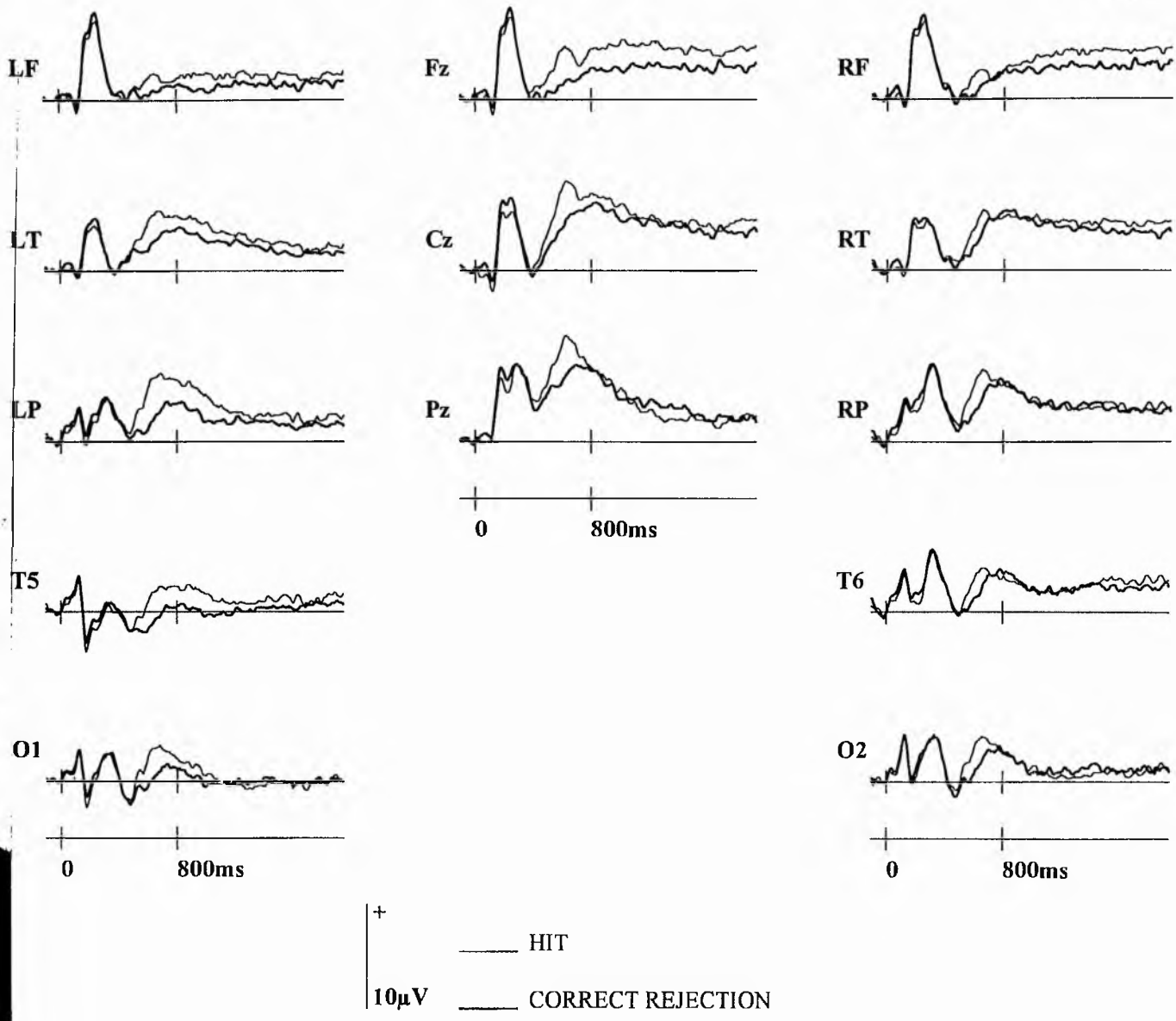


Figure 9.2 Grand average hit and correct rejection ERPs. See figure 4.2 legend for description of the site labels.

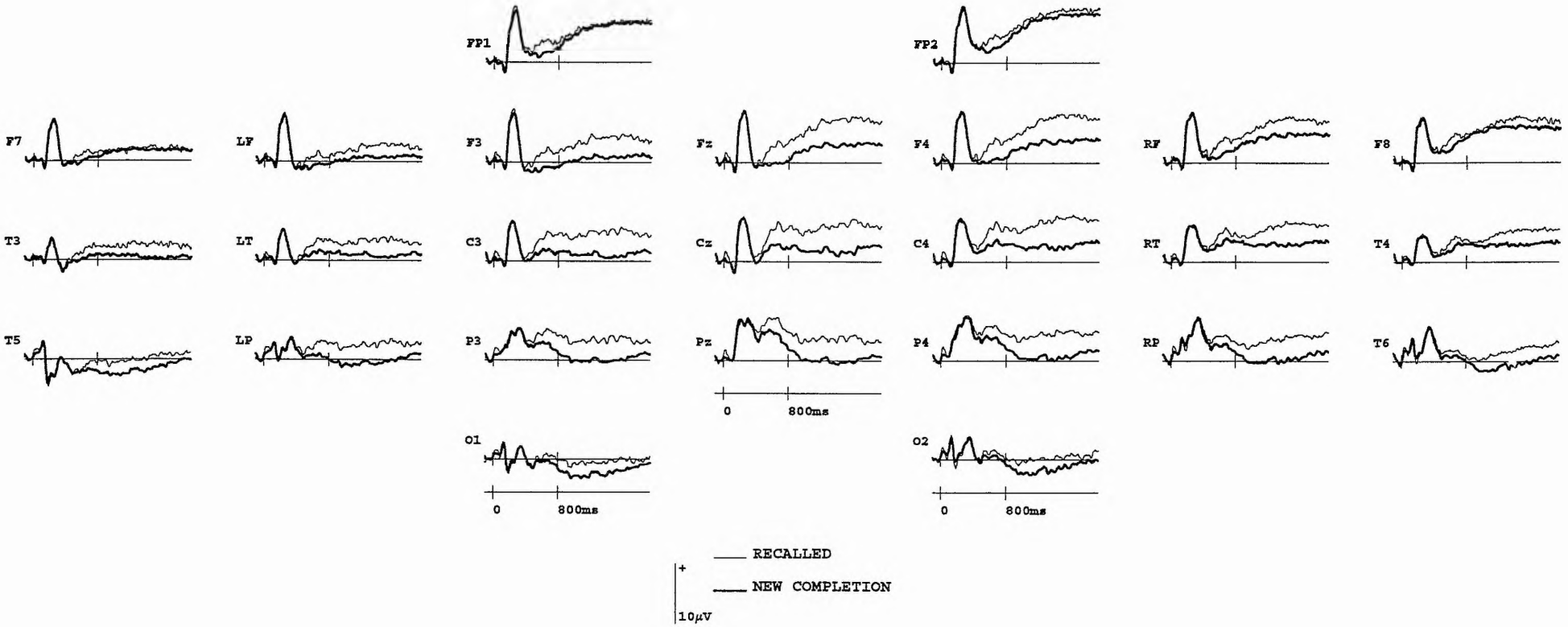


Figure 9.3 Grand average ERPs evoked by stems correctly completed with studied items which are recognised (recalled ERPs), along with ERPs evoked by stems completed with unstudied items which are correctly rejected (new completion ERPs). Electrode sites as for figure 9.1.

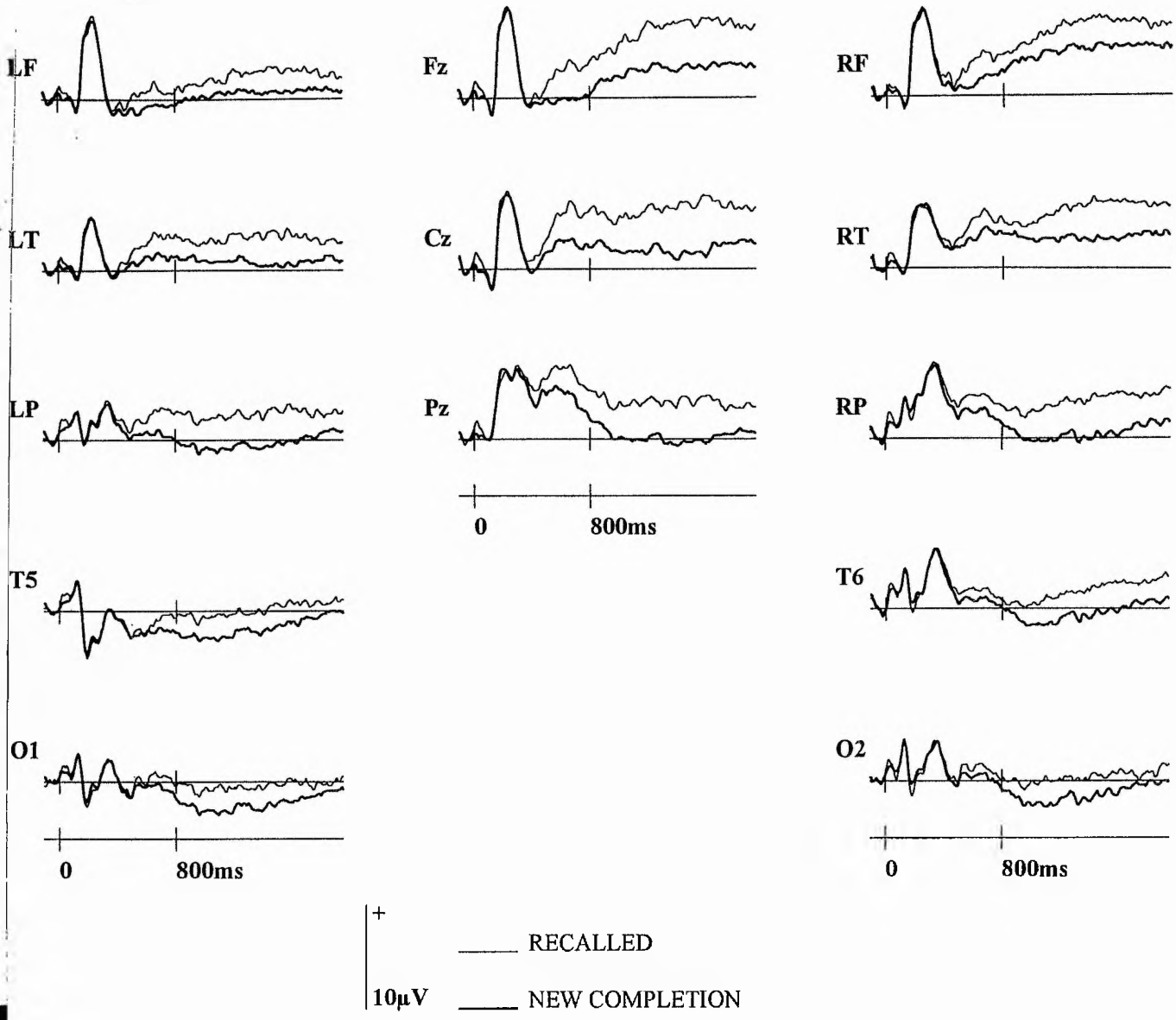


Figure 9.4 Grand average recalled and new completion ERPs. Electrode sites as for figure 9.2.

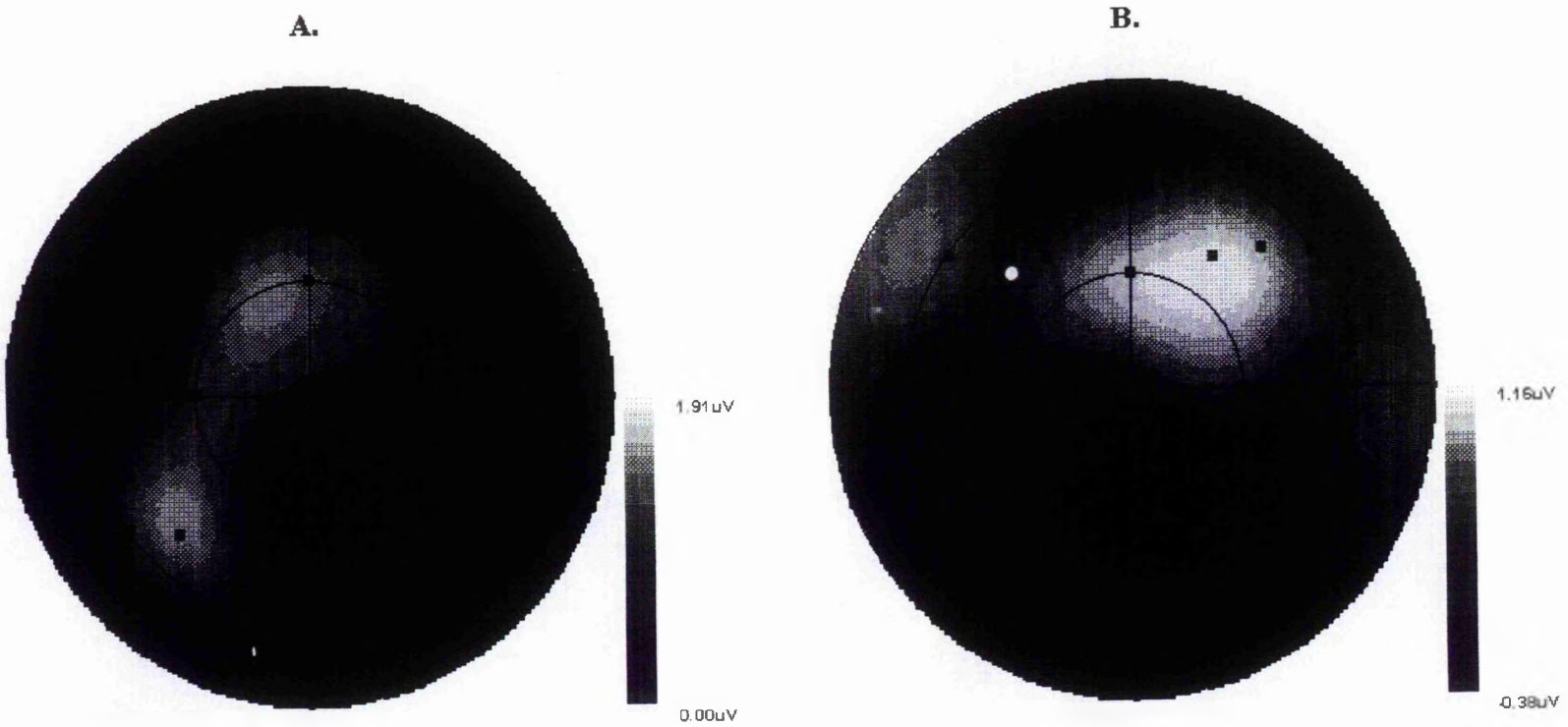


Figure 9.5 Topographic voltage maps for the recognition memory ERP effect, showing the relative amplitude of the differences between hit and correct rejection ERPs over the (a) 400-1200ms and (b) 1200-1944ms latency regions, incorporating all 25 electrode sites. The scale bar to the right of each map indicates the mean maximum and minimum values of the magnitude of the old/new effect across all electrode sites during the selected latency regions.

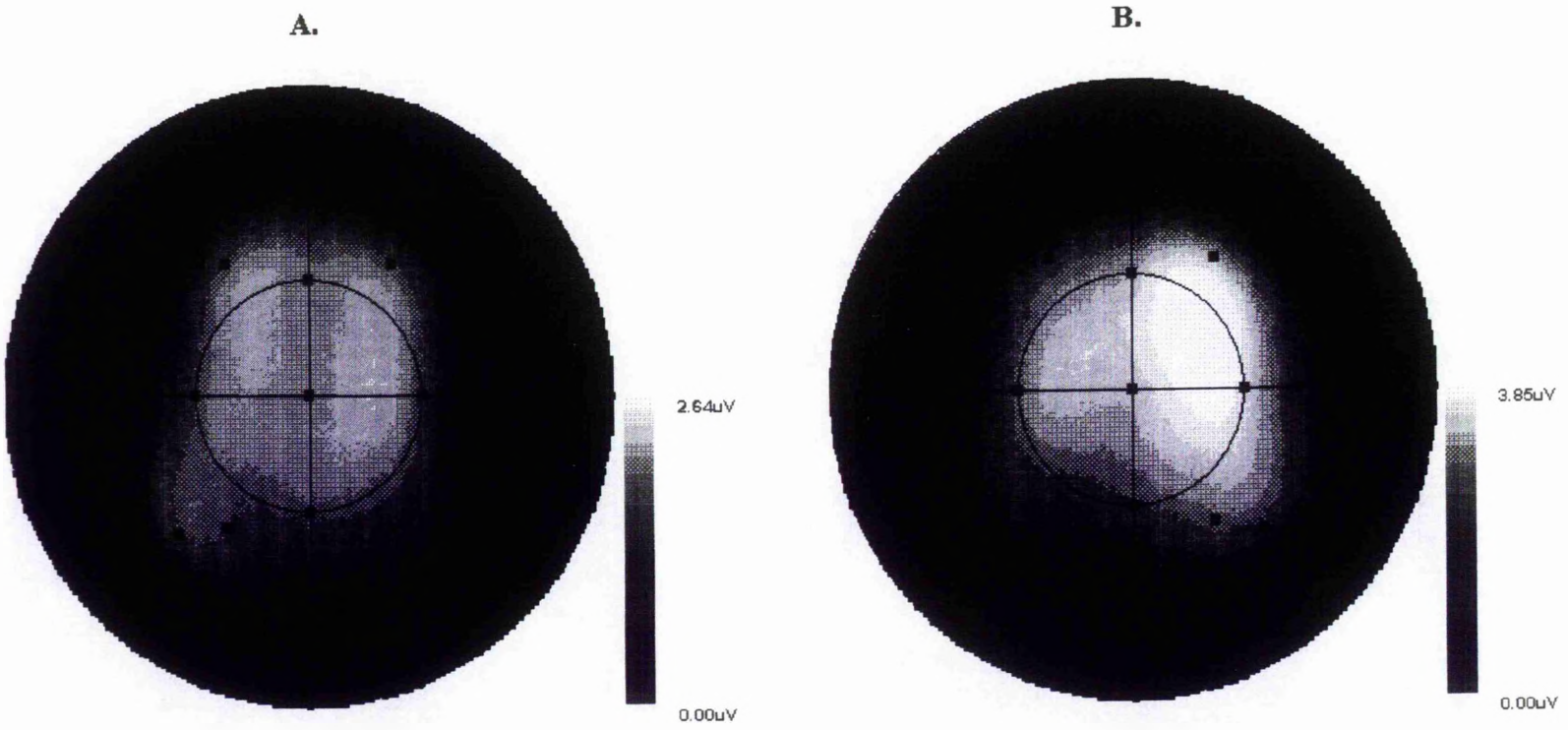


Figure 9.6 Topographic voltage maps for the cued recall ERP effect, showing the relative amplitude of the differences between studied and unstudied completion ERPs over the (a) 400-1200ms and (b) 1200-1944ms latency regions, incorporating all 25 electrode sites. Scale bar as for figure 9.5.

10.0 Cued Recall of Item and Source Information: An Event-Related Potential Study

10.1 Introduction

This study investigates the nature of the processes contributing to the cued recall ERP effect. This is done by employing an operational definition of recollection which differs from that employed in the studies carried out so far. In the previous studies, the operational means of distinguishing recollected and unrecollected items involved an overt recognition judgment for the item used to complete each stem. Correct completions which were recognised as such were assumed to have been associated with explicit memory. Quite clearly, if a subject is prepared to endorse a completion as studied, and they are not merely guessing, then they are explicitly aware of the prior occurrence of that item at study, in some sense. The further assumption which was made in the previous studies was that the explicit memory thus evinced reflected the recollection of details of the episode in which the item was presented for study. The purpose of the present experiment is to directly test this additional assumption.

The operational definition of recollection applied in this study takes advantage of the widely held belief that recollection is perhaps best understood as the explicit retrieval of information from particular prior episodes (e.g. Jacoby and Kelley, 1992; Tulving, 1983). Based on this assumption, it is possible to create tasks which require specific attributes of study episodes to be explicitly retrieved and reported. Such tasks assess 'source memory' (Johnson, Hashtroudi and Lindsay, 1993). It is helpful at this point to distinguish between two kinds of source memory task. In the first, the source attribute to be retrieved is some aspect of the content of the study episode itself - such as the study modality in which an item was presented (auditory or visual). Source memory tasks of this type have been used successfully by Wilding and

colleagues to investigate the nature of the processes responsible for generating 'old/new ERP effects' (see chapter 3).

A second kind of source task involves reporting when and where a particular prior episode occurred, again using a test item as a retrieval cue. To make this more clear, to a first approximation, episodes clearly have two aspects, their contents (i.e. perceptions, reflections, recollections and so forth), and their spatiotemporal coordinates (i.e. when and where they occurred). For example, tasks involving 'recency judgments' are sometimes used to assess memory for when items were presented (e.g. Janowsky, Shimamura and Squire, 1989). That is, when required to judge which of two items was experienced most recently, correct performance may be achieved by discriminating the temporal order of the respective episodes in which each item was presented. Thus, in order to discriminate temporal order, the respective episodes must be retrieved. The basis for the temporal order discrimination itself is far from clear. As argued elsewhere in this thesis (e.g. chapter 1), the role of the frontal lobes as 'working-with-memory' (Moscovitch, 1992; 1994) structures may include such processes as are necessary to the ability to discriminate temporal order.

In the present study, subjects are required to judge in which of two successively presented word-lists their correct completions to word-stems were studied. The task thus requires subjects to discriminate the relationship between a particular episode in which an item is presented, and the wider context specified by the list in which the item was presented. The critical point underlying the use of this task is that in order to perform the list discrimination correctly, subjects will be required to recollect and then further process details of the study episode.

The present study thus involves a source memory task which may bear similarity to a 'recency memory' study carried out by Tendolkar and Rugg (submitted). Tendolkar and Rugg made subjects study single words presented in two successively presented lists. At test, subjects were presented with word-pairs consisting either of two old items (one from each study list, 'old-old' pairs), one old and one new item ('old-

new' pairs), or two new items ('new-new' pairs). The task required judging which of the two items had been presented most recently (i.e. in the second list from the study phase).

Tendolkar and Rugg did not provide an account of how the recency judgment could be made. However, one possibility is that subjects may attempt to recollect the previous occurrence of the episodes on which the items were presented, and by so doing come to a decision as to their respective temporal order. If this account is correct, then it is plausible to suggest that ERP old/new effects may be observed for pairs which contain either one or two old items. Further, if the magnitude of the parietal old/new effect does reflect the amount or quality of recollected information (see chapter 3), it may be predicted that ERPs for old-old pairs would exhibit a larger parietal old/new effect than those for old-new pairs, where only one old item is presented. Furthermore, if a frontal old/new effect reflects the use of retrieved information per se, then the requirement to discriminate temporal context may elicit a frontal effect. Consistent with these notions, a number of researchers have likened recency judgments to a form of source memory (Johnson, Hashtroudi and Lindsay, 1993; Janowsky, Shimamura and Squire, 1989; Schacter, Harbluk and McLachlan, 1984; Moscovitch, 1994). In this case, the source attribute to be discriminated is the temporal context of the episode in which the item was presented at study.

Tendolkar and Rugg found that ERPs did exhibit parietal old/new effects for the old-old and old-new pairs, relative to the ERPs for new-new pairs. Furthermore, in line with the predictions given above, the magnitude of the parietal effect was largest for old-old pairs, where more information could be recollected since two old items were presented and not just one as in the old-new pairs. A frontally distributed ERP effect also distinguished the old-old pairs from ERPs in all other conditions. However, this effect was symmetrically distributed, and also tended to be larger at the most anterior fronto-polar electrode sites where right frontal old/new effects are typically reduced in magnitude (e.g. Wilding and Rugg, 1996). These findings led Tendolkar and Rugg to link their frontal effect with the operation of frontal lobe processes associated with the correct discrimination of temporal order.

This symmetrical frontal effect thus differs critically in terms of its scalp distribution from the right frontal old/new effect first identified by Wilding and Rugg (1996). This difference is suggestive of a qualitative difference in processing across the tasks. One possibility is that this qualitative difference may reflect differences in the nature of the processes which support different kinds of source judgment.

Given that frontal ERP effects vary with the type of task employed, it is to be hoped that the present study will provide results which converge, rather than diverge, on a consistent general account. So, given that there is similarity in kind between the source task used here and the recency task employed by Tendolkar and Rugg, it is at least conceivable that a symmetrical frontally distributed ERP effect will be observed here. By employing a long recording epoch (2s), the present study will show whether the late right anterior focus of the cued recall effect (observed in experiment 5) is also present here. It may be, for example, that the overt requirement to make source judgments in the present study will result in the modulation of these late regions of the cued recall ERP effect, such that a more symmetrical anterior effect will be observed.

ERPs from three critical conditions are contrasted in the present study. These are: 1) ERPs evoked by stems attracting correct completion and a correct assignment to study list (termed *hit-hit* ERPs); 2) ERPs evoked by correctly completed stems incorrectly assigned to study list (*hit-miss* ERPs); and 3) ERPs evoked by stems completed with correctly rejected unstudied items (*correct rejection* ERPs). The contrast between correct rejection ERPs and ERPs in the other two conditions will allow ERP effects associated with explicit memory to be identified once more. The further contrast between the hit-hit and hit-miss ERPs will, in addition, show whether the generators of the ERP effects are involved with the recollection of the item and/or the source attribute.

10.2 Method

10.2.1 Design Overview

As for experiment 5, the present study employed a blocked design consisting of four identical study/test phases. In total, each subject studied 160 critical items, with two twenty item lists presented at each study phase. Memory for studied items was assessed using a word-stem cued recall task which, in addition, required a further list judgment whenever a completion was deemed to have been a studied item.

10.2.2 Subjects

Subjects were 21 young adults, each paid £3.50 per hour. The data from three subjects were discarded because each failed to complete all four study/test blocks, and therefore did not provide sufficient trials to form ERPs in critical conditions. Data from a further two subjects was also discarded, since their memory was too poor to provide sufficient trials in critical conditions. Of the remaining 16 subjects, 9 were female and all were right handed. Their mean age was 19.7yrs (range 18-23). All subjects were native English speakers, with normal or corrected-to-normal eyesight.

10.2.3 Stimuli

The stimuli were taken from the new set of experimental items (see chapter 7), and consisted of a pool of 320 words. The first three letters, or stem, of each word was unique. The pool of 320 words was partitioned at random into two sets of 160 critical words. Half of the subjects studied one set of critical items, and the remaining subjects studied the other set. Each set of 160 critical items was divided into four pairs of 20 item study lists (designated list 1 and list 2), with 2 buffer items at the beginning and the end of each list. At each study phase, a pair of 20 item lists was presented. The order of list presentation was counterbalanced across subjects, such that half of the subjects saw list 1 first in each block, while the other half saw

list 2 first. The particular pair of lists which were studied in each block was also rotated across subjects.

Each test list comprised 40 critical stems belonging to studied items, plus 40 'new' stems drawn from the set of 160 items which were not studied. Two different orderings of items in each test list were created. Thus, each study list pair had two corresponding test lists, each containing 80 word stems, and 2 unstudied 'buffer' stems at the beginning of each list.

Stimuli were presented at both study and test in upper case on a TV monitor (white on a black background). Word stimuli subtended maximum horizontal and vertical visual angles of 1.5 degrees and 0.4 degrees, respectively. Word-stems subtended maximum horizontal and vertical visual angles of 0.5 degrees and 0.4 degrees. The presentation of study items was paced by the experimenter. Each study item was presented at the centre of the screen, and remained on screen until the subject gave a response (see below). The screen was blanked after each response, and then the next item was displayed.

Each test phase trial began with the display of a cue at the centre of the screen ('X'). The cue remained on screen for 1s, and was followed immediately by a fixation asterisk displayed at the same position. The asterisk also remained on the screen for 1s. The screen was then blanked for 120ms, after which the stimulus was displayed for 300ms, centred on the position occupied by the fixation asterisk. The screen was then blanked for 2.7s, after which a question mark was displayed to indicate that a verbal response was now required (see below). After a 3s interval to permit a response to be made, the task cue for the next trial was displayed.

10.2.4 Procedure

Once the recording cap had been applied, subjects were seated in front of the stimulus presentation monitor. They were informed that their memory for words would be assessed in four study/test blocks, and that in each block two twenty item

lists would be presented one after the other for study. Subjects were further informed that the test phase involved assessing memory both for the items and the list in which they were studied. The study task involved generating a sentence containing each presented item, which was to be spoken aloud. The experimenter listened to the sentence, and initiated the display of the next item following each response. If the subject was unable to form a sentence within approximately 10s, the next item was displayed. The duration of each study phase averaged about 5 minutes. On completion of each study phase, subjects were given a two minute rest.

In each test phase, subjects were informed that they would see a list containing 80 word-stems, of which half belonged to studied items. Instructions were to attempt to recall a studied item belonging to each stem, and in addition the list in which the studied item was presented. If recall was impossible, the stem was to be completed with the first suitable word to come to mind. Responses were to be withheld until the appearance on the monitor of a question mark. If the completion was judged to be an unstudied item, then the required response was to first of all say the completion, then to say 'new'. If the completion was judged to be a studied item, but presentation list could not be recollected, then the required response was to first of all say the completion, then say 'don't know'. Subjects were explicitly instructed not to guess the list in which the item had been presented. If presentation list could be recollected, the required response was to first of all say the completion, then to say either "ONE" indicating the first study list, or "TWO" indicating the second study list. Finally, subjects were instructed not to guess whether a given completion was studied or not. If in doubt, subjects were told to say 'new'. The duration of each test block was approximately 15 minutes. Subjects were given a short rest break halfway through each block.

To minimise EEG artefact, subjects were instructed to remain as relaxed and as still as possible during each trial. They were further instructed to refrain from blinking during the period beginning with the display of the fixation asterisk and ending with the display of the question mark.

10.2.5 ERP Recording

All aspects of EEG recording were identical to those given for experiment 5 (see Chapter 9).

10.3 Results

The critical ERPs were evoked in conditions where stems were correctly completed with studied items, and where the accompanying list decision was correct or incorrect. ERPs could not be formed for these conditions as a function of the list in which retrieved items were presented at study, because there were never sufficient trials to do so. Therefore, in the analyses which follow, the ERP data have been collapsed across the factor of study list. However, this factor was included in the analyses of the behavioural data reported below.

10.3.1 Behavioural Data

The behavioural data from the 16 subjects contributing to the ERPs are summarised in Table 10.1. The mean recall rates (indicating the rate of explicit item retrieval [8]) for items from study lists 1 and 2 were 45.9% and 51.0%, respectively. Items from list 1 were recalled less often than items from list 2 ($t(15) = 2.27$, $p < 0.05$). To assess memory for study list, the proportions of retrieved items attracting correct and incorrect list assignments were contrasted. For items from list 1, more correct than incorrect list assignments were made ($t(15) = 9.12$, $p < 0.001$). However, for items from list 2, the proportion of correct and incorrect list assignments did not differ significantly. These findings indicate that subjects were not able to correctly place items from list 2 in their study context.

[8] Given the present task instructions, all correct completions for which subjects attempted the list judgment (or said don't know) must have been retrieved explicitly (with the exception of cases where correct completion resulted from a guess, and where the subsequent list judgment was therefore entirely based on a guess).

The above counterintuitive finding may be explained by consideration of the data pattern as a whole. If it is the case that subjects tended to guess 'list 1' when unsure, instead of using the don't know option, then the observed pattern of findings would occur. That is, the tendency to guess with 'list 1' would lead to an increase in the proportion of items correctly assigned to list 1, but would also increase the proportion of incorrect assignments for items from list 2. This is the pattern which was observed (see table 10.1). However, this interpretation of the findings cannot be verified since there is no way of establishing whether such a response bias actually operated. Of the false alarm responses, nearly 100% were associated with a don't know list judgment, which indicates that a bias to respond 'list 1' did not exist. However, extremely few false alarms were made, which casts doubt on the reliability of the false alarm data as an indicator of whether or not a bias existed.

As mentioned above, in order to carry out analyses of the ERP data it is in any case necessary to collapse across the factor of study list to create ERPs with adequate numbers of trials for the hit-hit and hit-miss conditions. With regard to the behavioural data, when collapsed across the factor of study list the mean recall rate for studied items was 48.4%. Of these correct completions, 0.42 were accompanied by a correct list judgment, 0.21 by an incorrect list judgment, and 0.36 by a don't know response. The probability of a correct list assignment was significantly greater than the probability of an incorrect list assignment ($t(15) = 6.13$, $p < 0.001$). Thus when collapsed across the factor of study list, subjects were able to reliably discriminate list. However, the contribution made by correct guesses to the apparent ability to correctly assign items to their context cannot be estimated. This issue is raised again in the discussion section below.

10.3.2 Event-Related Potentials

As noted above, insufficent trials were available to allow a contrast between ERPs evoked by stems completed with studied items as a function of the list in which the items were presented. ERPs were therefore formed for conditions collapsed across this factor. The critical comparison concerns ERPs evoked by correctly completed

stems as a function of whether list could be recollected. Conditions where correct completion is accompanied / unaccompanied by a correct list assignment are termed the hit-hit / hit-miss conditions, respectively. Note that the hit-miss condition comprises trials where incorrect list assigments and don't know judgements were made. Hit-hit and hit-miss ERPs are contrasted with ERPs evoked by stems completed with unstudied items which were correctly rejected as new (correct rejection ERPs).

The hit-hit, hit-miss and correct rejection ERPs are depicted in figure 10.1 (which shows ERPs from all 25 electrode sites) and in figure 10.2 (which focuses upon the 13 sites of the standard electrode montage). The mean number of trials in the ERPs was 27.7 (range 16-51), 37.9 (22-58) and 119.1 (69-142), respectively. As the figures show, the hit-hit and hit-miss ERPs each exhibit large sustained positive shifts, which onset around 400ms or so, with respect to the correct rejection ERPs. The positive shift is larger in hit-hit ERPs. In each case, the positive shift appears to be larger over the left than the right hemisphere electrodes, particularily from around 800ms onwards. During the latter part of the recording epoch the left > right asymmetry is less marked, though still present, while each effect appears more sustained over the anterior than the posterior sites (e.g. contrast Pz and Fz).

Finally, the onset latency of the differences between the hit-hit and hit-miss ERPs appears later than that differentiating these ERPs and the correct rejection ERPs, particularly at the anterior sites. Accordingly, the onset latency analyses are presented now, so as to provide additional information to guide the selection of latency regions for analysis.

10.3.2.1 Onset Latency Analyses

Estimates of the onset latency of the positive shifts in the hit-hit and hit-miss ERPs were determined by computing a series of point-by-point t-tests on subtraction waveforms representing each condition at each electrode site, as in the previous experiments. The waveforms were created by subtracting correct rejection ERPs

from the hit-hit ('hit-hit effect') and hit-miss ('hit-miss effect') ERPs. The analyses indicated that the hit-hit effect first onset at the right fronto-polar (Fp2) electrode at 408msec post-stimulus. The hit-miss effect first onset at 480ms at the midline Fz and right F4 electrodes. As noted above, the hit-hit and hit-miss effects diverge from one another some time after the onset of each effect. To quantify this, an onset latency analysis was applied to the subtraction waveforms from each site, produced by subtracting the hit-miss effect waveforms from the hit-hit effect waveforms. This latency analysis showed that the two effects first diverged at the left temporal electrode, at 688ms. At anterior sites, the effects first diverge slightly later at the Lf and F3 sites at 720ms. Thus the effects do not begin to diverge reliably from one another until nearly 300ms after they onset (i.e. 408ms vs. 688ms).

The above analyses provide an important constraint for the selection of latency regions. On their basis, it would seem appropriate to select an initial 400-700ms latency region in which to compare the hit-hit and hit-miss ERPs with the correct rejection ERPs, prior to the latency at which the hit-hit and hit-miss ERPs diverge. A broader latency region, for example the 400-1200ms region used in the previous experiment 5, would not be appropriate for this study, since this encompasses regions where the hit-hit and hit-miss ERPs appear to initially overlap and then subsequently diverge. Accordingly, in the analyses presented below, the mean amplitudes of the critical ERPs during the 400-700ms were contrasted by ANOVA.

As for all previous studies, the selection of further latency regions was based upon consideration of initial exploratory 100ms ANOVAs, covering consecutive 100ms regions, in this case beginning at 700-800ms. These indicated that throughout the entire 700-1944ms latency region, the differences between hit and correct rejection ERPs were statistically highly reliable. From around 1600ms, differences between these ERPs became more marked at the anterior sites, which is consistent with the impression gained from simple visual inspection of figures 10.1 and 10.2. Furthermore, these 100ms analyses also showed that the apparent hemispheric asymmetry of the modulations present in the hit-hit and hit-miss ERPs were most reliable during the 800-1600ms latency region. On the basis of these 100ms analyses,

three further broad latency regions were selected for detailed analyses. These regions were 800-1200ms, 1200-1600ms and 1600-1944ms.

The following analyses were performed upon ERP data from the 13 sites of the standard montage, allowing a comparison of the ERP effects obtained in the present experiment with the findings of the previous studies. As for all the previous studies in this thesis, these analyses employed ANOVA, conducted separately upon data from the midline and lateral hemisphere sites for all three conditions depicted in figure 10.2. The results reported below are for planned pairwise contrasts between ERPs from each condition (i.e. hit-hit vs. hit-miss; hit-hit vs. correct rejection; and hit-miss vs. correct rejection). In each case, the pairwise ANOVAs reported below were preceded by global ANOVAs contrasting all three conditions with one another. In all cases, these global ANOVAs gave rise to significant effects involving the factor of condition. The results of these global ANOVAs are not included here for reasons of brevity and clarity of exposition.

Additional planned subsidiary pairwise ANOVAs were carried out to analyse data from the lateral sites when a significant effect involving the factor of condition was observed. These ANOVAs used data from selected lateral electrode sites. The sites chosen were the left and right frontal and parietal electrodes (Lf/Rf/Lp/Rp), shown in previous studies to be most sensitive to the two components contributing to the memory-related ERP effects observed on tests of source memory (e.g. Wilding and Rugg, 1996). Finally, the analyses of data from the midine sites during each latency region are summarised first, since a similar pattern of effects occurred during each latency region.

10.3.2.2 Midline Sites

During each latency region, highly significant condition by site interactions were observed for the pairwise ANOVAs contrasting the correct rejection ERPs with ERPs from the other two conditions (see table 10.2 for a summary of the results of the relevant pairwise ANOVAs). In each case, these interactions reflected the fact

that the positive shifts in the hit-hit and hit-miss ERPs were largest at the more anterior midline (Fz and Cz) sites. In contrast, during the 400-700ms period, the hit-hit and hit-miss ERPs did not differ significantly from one another, a result which is consistent with the findings from the above onset latency analyses. Thereafter, the hit-hit ERPs were reliably more positive-going than the hit-miss ERPs, across all midline sites (see table 10.2).

10.3.2.3 Lateral Sites

10.3.2.3.1 400-700ms

The ANOVAs contrasting the hit-hit and hit-miss ERPs at the selected lateral sites did not give rise to a significant effect involving the factor of condition, which again confirms the results of the onset latency analyses. In the ANOVAs contrasting the hit-hit and hit-miss ERPs with the correct rejection ERPs, significant condition by site interactions were observed (hit-hit: [$F(1.9, 28.3) = 5.43$, $p < 0.005$]; hit-miss: [$F(1.4, 20.7) = 4.55$, $p < 0.05$]. The planned subsidiary ANOVAs at the selected lateral sites showed that the hit-hit ERPs were more positive than correct rejection ERPs at both the parietal and the frontal electrode sites, with main effects of condition observed in each case (parietal: [$F(1,15) = 6.24$, $p = 0.025$], and frontal: [$F(1,15) = 17.42$, $p = 0.001$]). The hit-miss ERPs were also more positive than the correct rejection ERPs at the parietal and the frontal sites, again main effects of condition were observed in each case (parietal, a marginally significant effect: [$F(1,15) = 3.53$, $p < 0.080$], and frontal: [$F(1,15) = 9.92$, $p < 0.0075$]).

10.3.2.3.2 800-1200ms

A main effect of condition occurred for the ANOVA contrasting hit-hit with hit-miss ERPs [$F(1,15) = 12.04$, $p < 0.005$], due to the enhanced positivity of the hit-hit ERPs. The ANOVAs contrasting the hit-hit and hit-miss ERPs with the correct rejection ERPs both gave rise to interactions between condition, hemisphere and site

(hit-hit: [$F(1.6, 23.6) = 3.46$, $p = 0.058$]; hit-miss: [$F(3.4, 51.2) = 3.98$, $p = 0.01$]). The results of the subsidiary ANOVAs at selected sites are given below.

The ANOVAs of data from the frontal sites gave rise to significant main effects of condition for hit-hit vs. correct rejection [$F(1,15) = 55.07$, $p < 0.001$], and hit-miss vs. correct rejection [$F(1,15) = 23.27$, $p < 0.001$]. In each case, the correct rejection ERPs were the more negative-going. The ANOVAs of data from the parietal sites gave rise to significant interactions between condition and site for hit-hit vs correct rejection [$F(1,15) = 22.25$, $p < 0.001$], and hit-miss vs. correct rejection [$F(1,15) = 12.08$, $p < 0.005$]. The interactions reflect the fact that the differences between the correct rejection ERPs and the hit-hit and hit-miss ERPs were larger over the left than the right parietal site (see figure 10.3a, which shows the mean amplitude of the difference between the correct rejection ERPs and the hit-hit and hit-miss ERPs during this latency region).

10.3.2.3.3 1200-1600ms

The ANOVAs showed that the hit-hit ERPs were more positive than the hit-miss ERPs (main effect of condition: [$F(1,15) = 8.17$, $p < 0.025$]. In the ANOVAs contrasting the hit-hit and hit-miss ERPs with the correct rejection ERPs, significant interactions between condition and hemisphere (hit-hit: [$F(1,15) = 6.28$, $p < 0.025$]; hit-miss: [$F(1,15) = 5.20$, $p < 0.05$), and condition and site (hit-hit: [$F(2.2, 32.5) = 13.82$, $p < 0.001$]; hit-miss: [$F(1.5, 22.4) = 8.90$, $p < 0.005$]) were observed. These interactions were elucidated by the subsidiary ANOVAs employing data from the selected lateral electrode sites, reported below.

The ANOVAs of data from the frontal sites gave rise to significant main effects of condition for hit-hit vs. correct rejection [$F(1,15) = 48.29$, $p < 0.001$], and hit-miss vs. correct rejection [$F(1,15) = 19.38$, $p = 0.001$]. In each case, the correct rejection ERPs were the more negative-going. The ANOVAs of data from the parietal sites gave rise to significant interactions between condition and site for hit-hit vs correct rejection [$F(1,15) = 7.08$, $p < 0.025$], and hit-miss vs. correct rejection [$F(1,15) =$

5.09, $p < 0.05$]. The interactions again reflect the fact that the differences between the correct rejection ERPs and the hit-hit and hit-miss ERPs were larger over the left than the right parietal site (as depicted in figure 10.3b).

10.3.2.3.4 1600-1944ms

The ANOVAs showed that the hit-hit ERPs were marginally more positive than the hit-miss ERPs (main effect of condition: [$F(1,15) = 4.24$, $p = 0.058$]). In the ANOVAs contrasting the hit-hit and hit-miss ERPs with the correct rejection ERPs, significant interactions between condition and hemisphere (hit-hit: [$F(1,15) = 5.41$, $p < 0.05$]; hit-miss: [$F(1,15) = 6.38$, $p < 0.025$]), and condition and site (hit-hit: [$F(2.6, 38.5) = 10.53$, $p < 0.001$; hit-miss: [$F(1.5, 22.6) = 5.64$, $p < 0.025$]) were observed. These interactions were once more elucidated by subsidiary ANOVAs employing data from the selected lateral electrode sites, reported below.

The ANOVAs of data from the frontal sites gave rise to significant main effects of condition for hit-hit vs. correct rejection [$F(1,15) = 22.09$, $p < 0.001$], and hit-miss vs. correct rejection [$F(1,15) = 9.37$, $p < 0.01$], which in addition gave rise to a significant condition by site interaction [$F(1,15) = 5.36$, $p < 0.05$]. In each case, the main effects of condition arose because the correct rejection ERPs were the more negative-going. The condition by site interaction arose because the hit-miss ERPs were more positive than the correct rejection ERPs only at the left frontal site. The ANOVAs of data from the parietal sites only gave rise to a significant interaction between condition and site for hit-hit vs correct rejection ERPs [$F(1,15) = 4.99$, $p < 0.05$]. This interaction is again due to the difference between the correct rejection ERPs and the hit-hit ERPs being larger over the left than the right parietal site (as depicted in figure 10.3c).

10.3.2.4 Summary

The hit-hit and hit-miss ERPs did not differ during the 400-700ms latency region. But during the subsequent 800-1200ms, 1200-1600ms and 1600-1944ms periods, the

hit-hit ERPs were the more positive at both midline and lateral sites. With respect to the correct rejection ERPs, both the hit-hit and hit-miss ERPs were more positive going from 400ms onwards. At the lateral parietal sites, this positive-shift was larger over the left than the right hemisphere from 800ms onwards. This hemispheric asymmetry in the magnitude of the positive-shift was not present at the lateral frontal sites.

10.3.3 Topographical Analyses (by Latency Region)

In the following comparisons, the scalp topography of the hit-hit and hit-miss effects is analysed. The topographic analyses were conducted upon subtraction waveforms from each electrode site. As for the onset latency analyses above, the waveforms were created by subtracting correct rejection ERPs from the hit-hit (hit-hit effect) and hit-miss (hit-miss effect) ERPs. The data were subjected to ANOVA after they had been rescaled (McCarthy and Wood, 1985; and see chapter 4).

Figures 10.4 and 10.5 show topographic maps of the two ERP effects during the four latency regions. During the initial 400-700ms period each effect is focused roughly over the midline Fz electrode, and distributed symmetrically over the lateral anterior electrodes. This anterior focus remains throughout the entire 400-1944ms period. During the latter part of the recording epoch (1200-1944ms), at anterior sites the hit-miss effect appears to be more symmetrically distributed about the midline than the hit-hit effect, whose anterior focus appears on and slightly to the right of the midline. In addition, the hit-miss effect appears more diffusely distributed over the anterior sites than is the hit-hit effect. During the 800-1200ms and 1200-1600ms periods, an additional more posterior left hemisphere focus emerges (particularily during the 800-1200ms period). During the 1600-1944ms region, the left posterior effect is less evident. Clearly, both effects are very similarly distributed during each latency region.

As for the above analyses of the raw ERP data, the topographical analyses used mean amplitude measures from all four latency regions. An initial global ANOVA was

carried out on the data from all four latency regions. This global ANOVA employed the factors of epoch, condition (hit-hit effect vs hit-miss effect) and electrode site. The global ANOVA gave rise only to a significant interaction between epoch and site [$F(5.5, 81.8) = 7.57$, $p < 0.001$], confirming the impression based on figures 10.4 and 10.5, that the topography of the two effects is essentially identical during each latency region, and further that each effect changes similarly over time. As further confirmation of this, ANOVAs contrasting the distribution of each effect at all sites during each latency region failed to give rise to a significant effect involving the factor of condition.

In the following analyses, subsidiary ANOVAs were conducted to show the nature of the changes in the distribution of the hit effect over time, using data from selected electrode sites. As in the previous studies in this thesis, these subsidiary ANOVAs employed data from the lateral anterior and posterior sites, specifically to assess differences in the symmetry of the ERP effects over the anterior and posterior electrode sites over time. In the ANOVAs reported below, the distribution of the hit-hit effect is analysed separately during each latency region. Each ANOVA employed the factors of epoch, chain (anterior vs. posterior), hemisphere and site (analogous ANOVAs of the hit-miss effect revealed an identical pattern of effects).

10.3.3.1 400-700ms

The ANOVA gave rise to a marginally significant main effect of chain [$F(1,15) = 4.13$, $p = 0.061$]. This reflected the symmetrical anterior > posterior gradient of the hit-hit effect. In addition, the main effect of site was significant [$F(1.1, 15.9) = 6.79$, $p < 0.025$]. This reflected the focus of the hit-hit effect over the scalp midline, and its gradual symmetrical diminution with distance from this focus.

10.3.3.2 800-1200ms

The ANOVA gave rise to significant chain by site [$F(1.6, 23.3) = 25.17$, $p < 0.001$] and hemisphere by site interactions [$F(1.5, 22.1) = 6.41$, $p < 0.025$]. The chain by

site interaction again simply reflected the symmetrical diminution of the hit-hit effect from its midline focus which was only present at the anterior electrodes. At the posterior electrodes, the hit-hit effect was more evenly distributed across the lateral sites. The hemisphere by site interaction was caused by the left > right asymmetry of the hit-hit effect, which was most pronounced at the sites most distant from the midline.

10.3.3.3 1200-1600ms

The ANOVA gave rise to a significant three-way interaction between chain, hemisphere and site [$F(1.4, 20.8) = 8.40$, $p = 0.005$]. To further elucidate the interaction, two subsidiary ANOVAs were carried separately on data from the anterior and posterior electrode sites. Each ANOVA employed the factors of hemisphere and site.

For the anterior electrode sites, the ANOVA gave rise to a significant hemisphere by site interaction [$F(1.3, 19.4) = 7.48$, $p < 0.01$]. As close inspection of figure 10.4 shows, this interaction appears to reflect that over the left hemisphere sites the effect extends more laterally, whereas over the right hemisphere sites the effect is more restricted to sites close to the midline. In addition, the focus of the effect is on and slightly to the right of the midline. This can be clearly seen in figure 10.6a, which plots the mean rescaled amplitudes of the effect at all the anterior lateral sites. For the posterior sites, the ANOVA gave rise to a significant main effect of hemisphere [$F(1,15) = 12.14$, $p < 0.005$]. In this case, the effect reflects the left greater than right posterior asymmetry of the hit-hit effect.

10.3.3.4 1600-1944ms

The ANOVA again gave rise to a significant three-way interaction between chain, hemisphere and site [$F(1.4, 20.7) = 6.10$, $p < 0.025$]. The interaction was elucidated using subsidiary ANOVAs performed separately for data from the anterior and posterior electrode sites. The ANOVAs employed the factors of hemisphere and site.

For the anterior electrode sites, the ANOVA gave rise to a significant hemisphere by site interaction [$F(1.3, 19.6) = 5.27$, $p = 0.025$]. As for the earlier 1200-1600ms latency region, this interaction appears to reflect the diminution of the hit-hit effect with distance from the anterior focus situated on and just to the right of the midline, and that the effect extends more laterally over the left than the right hemisphere sites (see figure 10.6b). For the posterior sites, the ANOVA gave rise to a significant main effect of hemisphere [$F(1,15) = 10.75$, $p = 0.005$], which again reflects the left greater than right asymmetry of the hit-hit effect.

10.3.3.5 Summary of the Topographical Analyses

Each effect was found to be essentially identical in scalp distribution. In addition, each effect appeared to be composed of two distinct components. At onset, the effects were initially symmetrically distributed about an anterior, approximately midline, focus. This anterior focus remained throughout the entire duration of each effect, while a more posteriorly distributed asymmetry (left greater than right) was present only from 800ms onwards. In the late 1200-1944ms period, at anterior sites the effect extended more laterally over the left than the right hemisphere sites, and became focused on and to the right of the scalp midline. The greater extension of the effect over the left hemisphere sites may have been because of summation of the activity of the left> right posterior component and the slightly right>left anterior component.

10.4 Discussion

When collapsed across the factor of study list, approximately half of all studied items were explicitly retrieved at test (48.4%). For these explicitly retrieved items, more correct than incorrect list judgments were made, indicating that study list could be reliably discriminated. However, it is clear from the behavioural data that completion of a stem with a recognisable studied item is not by any means always accompanied

by the recollection of the list in which the item was studied. First of all, when the factor of study list was taken into account, the analysis of the behavioural data showed that a response bias was probably operating, such that when unsure, and unwilling to respond with don't know, explicitly retrieved items were assigned to study list 1. Therefore, an unknown proportion of hit-hit responses for items from list 1 were probably made on the basis of a guess. Conversely, this makes it likely that hit-hit responses for items from list 2 were more likely to have reflected a genuine influence of memory. In summary, when collapsed across the factor of study list, the hit-hit condition is likely to have comprised some proportion of trials on which the correct response was not made on the basis of having recollected the study episode.

For the purposes of the interpretation of the ERP data, it is critical that the probability of recollection (defined in terms of ability to discriminate study list) should reliably differ across the hit-hit and hit-miss conditions. Although the above remarks indicate that a response bias may have existed, this does not imply that study list could not be recollected at all. While an unknown proportion of correct list assignments could have resulted from a guess, the remainder will have resulted from the influence of memory. More critically, when considered in relation to the hit-miss condition, where the probability of correct list assignment was by definition zero, the hit-hit condition must comprise more trials where study list was recollected, though the exact proportion remains unknown. In short, the hit-hit and hit-miss conditions do differ in the proportion of their constituent trials on which study list was recollected.

Finally, the fact that a correct list judgment could only be given overall for 42% of correctly recalled items indicates that the processes mediating recall of item information do not 'automatically' provide source information. This finding is consistent with previous neuropsychological studies of frontal and medial temporal lobe patient groups, which have shown that the recollection of item and contextual information does not depend upon identical neural structures, and hence memory functions (e.g. Glisky, Polster, and Rothieaux, 1995, and see chapter 1).

The critical ERP finding was that ERPs evoked by stems attracting the explicit retrieval of studied items were more positive-going than those completed with correctly rejected unstudied items. The size of this positive-going shift was larger in ERPs for explicitly retrieved items correctly assigned to study list (the hit-hit effect). Failure to give a correct list judgment was associated with a smaller, though still highly significant, ERP modulation (the hit-miss effect).

The topographical analyses indicated that the hit-hit and hit-miss effects had essentially identical scalp distributions. In addition, the distribution of both effects changed similarly over time. The change in distribution appears to have reflected the contribution of two topographically and temporally distinct components to the ERP modulations. From around 700-800ms onwards, a posterior and asymmetrical (left greater than right) component was evident. But from initial onset (circa 400ms), and throughout the whole of the remaining recording epoch, each effect also exhibited an anterior focus roughly centred on the midline. Late in the recording epoch this anterior effect was more extensive over the anterior left hemisphere sites. It is probable that this apparent extension of the effect at left anterior electrodes reflects the summation of the activity of the anterior and posterior components, resulting in relatively more positivity at far lateral left than right hemisphere sites. Thus, the activity of the anterior component may be more focused on and to the right of the scalp midline than is apparent.

In conjunction, the analyses of the raw ERP data, and the topographical analyses, suggest that the only difference between the hit-hit and hit-miss effects lay in the magnitude of the activity associated with each of the two underlying components. The activity of each component appeared to be increased in the hit-hit condition, where accurate source judgments were made. In keeping with the notion that the observed ERP effects reflect the contribution of (at least) two components, the following discussion will deal with functional interpretations of each, in turn.

10.4.1 The Parietal ERP Effect

The left greater than right posteriorly distributed component of the ERP effects bears more than a passing resemblance to the well-studied parietal old/new effect. As noted elsewhere in this thesis, it is highly likely that the parietal old/new effect reflects explicit retrieval processes delivering sufficient information at least to allow studied items to be judged as such. The cued recall ERP effect observed in experiment 4 also took the form of an asymmetrical, posteriorly distributed positive shift (see figure 8.5a). It would thus appear that the present study provides additional support for the suggestion, first put forward in the discussion for experiment 4, that parietal old/new effects may provide a quite general index of retrieval processes on tests which, intentionally or otherwise, engage explicit memory. So far as is indicated by the ERP findings, these retrieval processes appear to be quite insensitive to the manipulation of retrieval cues from whole words to word-stems.

As to why the parietal component was not evident in all the studies of cued recall presented in this thesis, two related answers may be given. First, in the previous studies the generators of the parietal effect could have been activated, but their scalp ERP correlates may have been swamped by the propagation of the more symmetrically distributed activity of the anterior component. It is evident from the present ERP data that the activity of the two components partially overlaps, both spatially and temporally. The findings from experiment 4 are in accord with this proposal. In that study, the parietal effect may have been observed in isolation, as it were, from the more anterior effect, which did not occur. That is, in order for the parietal effect to be observed in a 'standard' test of cued recall (as used in experiment 4), a manipulation may have to be introduced which reduces or eliminates the processing reflected by the more anterior component of the cued recall ERP effects. The methodology used in experiment 4 may have introduced just such a manipulation (for more detail see the discussion from chapter 8).

Another possible reason for the absence of the parietal effect in previous studies is as follows. In general, the parietal effect takes the form of an hemispheric asymmetry

in the magnitude of differences between ERPs in hit and correct rejection conditions. In their studies of old/new effects on tests of recognition memory, Rugg and colleagues have shown that the magnitude of the parietal old/new effect appears to vary with the amount or quality of information retrieved (see chapter 3). A similar suggestion is made by Wilding and Rugg (submitted) to account for differences in the magnitude of the parietal effect they observed as a function of hit-hit ERPs for 'spoken' and 'heard' items at study. If correct, this account suggests that the occurrence of the parietal effect in the present study reflects the retrieval of more information from the study episode than occurred on average in the previous studies where a parietally distributed left > right asymmetry was not observed (e.g. experiment 1, chapter 5).

The above account should also be considered in light of the very different instructions given in the present and in the previous studies of cued recall. Previously, episodic retrieval was 'sufficient' if it served to deliver a correct completion which could be recognised as such. But in the present study, retrieval of the studied item alone may not have been a sufficient basis on which to make discriminations regarding the temporal context in which the item was presented. For this additional source judgment, the retrieval of more episodic detail may have been facilitatory. Indeed, the present finding that the activity of the parietal component was increased for hit-hit relative to hit-miss ERPs fits well with this account. That is, correct source judgments appear to be correlated with an increase in the magnitude of the parietal effect, which may in turn reflect the retrieval of more episodic detail. If this account is correct, it would appear that in the present study accurate source judgments were associated with the retrieval of more information from the study episode. This cannot be considered an unreasonable conclusion, since the retrieval of increased detail concerning the study episode must facilitate (it surely cannot impede) the additional processing reflected by the frontal component, which may be more related to the source judgment (see discussion below).

Finally, the onset latency of the parietally distributed cued recall ERP effect in experiment 4 (approximately 1s) was substantially delayed with respect to the onset

of the similar effect on the recognition task included as part of that study. The onset of the left parietal effect in the present study (circa 700-800ms) was also delayed relative to that normally observed in studies of recognition memory. Assuming that the functional interpretation of the parietal effect is basically correct, these findings indicate that retrieval processing in the present study and in experiment 4 was substantially delayed with respect to that typically observed for recognition memory.

10.4.2 The Frontal ERP Effect

The findings of the present study provide new information concerning the nature of the processing reflected by the frontally distributed component of the cued recall ERP effects. In this study, the hit-hit ERPs were reliably more positive-going than the hit-miss ERPs. This enhanced positivity was present at both midline and lateral electrode sites throughout the recording epoch from 800ms onwards. In terms of absolute magnitude then, the hit-hit effect was larger than the hit-miss effect. Given that both effects resulted from the contribution of two partially overlapping underlying components, it seems clear that the activity of both components must have been enhanced in the hit-hit ERPs.

The present findings thus indicate only a quantitative difference in ERP effects as a function of the success of the source judgment. This finding is analogous to that presented by Wilding and Rugg (1996) in their study of source memory for gender of speakers' voice at study, where right frontal old/new effects were reliably more sustained late in the recording epoch for hit-hit vs. hit-miss ERPs. The present data therefore indicate that the frontally distributed component of the present ERP effects is affected by the success of the source judgment. This indicates that the component reflects processes which may play some role in the source discrimination itself.

The present anterior effect resembles the cued recall effect observed in experiment 5. In this study and in experiment 5, at anterior sites the cued recall effect was focused on and just to the right of the scalp midline. At anterior electrode sites, the cued recall effects differ slightly from the right frontal old/new effects observed by

Wilding and colleagues. The difference is in terms of the degree of asymmetry (right > left) which the effects exhibit at these anterior sites. In Wilding and colleagues studies of source memory the asymmetry is generally more marked. These differences in the degree of asymmetry suggest that there may be some difference in the processing which is reflected by the anterior effects across the studies. It is not clear whether this difference should be considered qualitative, simply on the basis of the slight differences in degree of hemispheric asymmetry across the tasks. It is therefore possible that similar processes are engaged on cued recall and in tests of source memory, and that these processes each give rise to frontal ERP effects which are larger to the right of the scalp midline.

The frontal effect observed in this study does not however resemble the frontal old/new effect observed by Tendolkar and Rugg (submitted) in their study of recency memory (see Introduction). The distribution of the frontal effect observed in the recency study was maximal at the fronto-polar electrode sites, and was in addition more clearly symmetrical over the hemispheres than was the case in the present data. Thus the ERP effects do not provide clear evidence for a similarity in the processing engaged on the present test of source memory and that engaged by the requirement to make recency judgments, despite the fact that both kinds of task would seem to involve judging the temporal context in which previous episodes occurred. However, since Tendolkar and Rugg also found sustained positive-going frontal ERP modulations, it seems likely that the processing on the recency task and in the present study may have some common features, at least in terms of the sustained neurophysiological mechanisms required to generate these particular kind of ERP effects.

10.4.3 A Third ERP Component?

A final *new* question posed by the present findings concerns the relationship between the processes reflected by the two components underlying the ERP effects. In this study the anterior effect occurred prior to the onset of the parietal effect, as judged both by the onset latency analyses, and the analyses of raw and rescaled mean

data from the 400-700ms latency region. At onset, the anterior effect was quite symmetrically distributed over the anterior electrodes, and it was not until later in the recording epoch (1200ms onwards) that any evidence, however slight, was found for a right>left asymmetry at anterior sites. These findings indicate that three components may contribute to the ERP effects. In addition to the left parietal component and the late frontal component which is slightly asymmetrical, there may be another early frontal component which is more symmetrically distributed.

Given that the early frontal effect occurs prior to the parietal effect, it seems unlikely that the early frontal effect is contingent on the successful outcome of the processing reflected by the parietal effect; if the parietal effect does reflect successful episodic retrieval, then the early frontal effect cannot be contingent upon successful retrieval. This issue is perhaps best addressed in a discussion of the findings from all of the studies presented in this thesis. Accordingly, the issue is raised in the next, and final, chapter, in which the general discussion is given.

10.5 Summary and Conclusions

The present findings provide further evidence that ERPs can be employed to illuminate different memory functions directed at the manipulation of information re-activated from store in long-term memory. The converging finding that different kinds of source judgment are associated with anteriorly distributed ERP effects also suggests a direction for the further study and fractionation of processing associated with the manipulation of information retrieved from long term memory. The present results also provide further evidence for the generality of the parietal old/new effect as a correlate of explicit retrieval processes, across disparate tests of memory.

This was the final empirical study to be presented. In the general discussion chapter which follows, the main findings and conclusions of each study will be summarised in order to effect an organisation on the material as a whole. This will allow me to indicate the ways in which the six presented studies contribute knowledge to the

field. In addition, possible future directions for the research programme begun here will be given in more detail.

Table 10.1 Behavioural Data for experiment 6. Shown separately for stems belonging to studied and unstudied items. Data for studied items are given separately as a function of study list (1 vs. 2) and also collapsed across the factor of study list, to give overall values. Column 1 shows the recall rate (i.e the proportion of stems correctly completed with explicitly retrieved studied items, collapsed across all the list decision categories). The value for unstudied items represents the baseline rate of completions with unstudied items from the experimental item-pool. Columns 2-4 show the conditional probabilities for correct (hit-hit), incorrect (hit-miss) and don't know (hit-DK) list judgments, given correct completion with a studied item. Column 5 shows the false alarm rate, defined as the proportion of stems completed with unstudied items *not* accompanied by a new response (collapsed across the correct, incorrect and don't know list judgments). Standard deviations are shown in brackets.

	RECALL RATE (%)	P(HIT-HIT)	P(HIT-MISS)	P(HIT-DK)	FALSE ALARM RATE (%)
STUDIED					
list 1	45.9 (12.4)	0.55 (0.18)	0.10 (0.07)	0.35 (0.18)	--
list 2	51.0 (14.0)	0.31 (0.14)	0.33 (0.09)	0.37 (0.19)	--
overall	48.4 (12.4)	0.42 (0.01)	0.21 (0.08)	0.36 (0.08)	--
UNSTUDIED	7.8 (1.8) (baseline completions)	--	--	--	1.7 (1.6)

Table 10.2 Summary of pairwise ANOVAs employing data for the hit-hit (HH), hit-miss (HM) and correct rejection (CR) ERPs at midline sites during the 400-700ms, 800-1200ms, 1200-1600ms and 1600-1944ms latency regions.

	400-700ms	**800-1200ms**	**1200-1600ms**	**1600-1944ms**
HH vs. HM	no sig. effects	condition main effect $F(1,15) = 7.08$, $P < 0.025$	condition main effect $F(1,15) = 5.53$, $P < 0.05$	condition main effect $F(1,15) = 4.13$, $P = 0.060$*
HH vs. CR	condition x site effect $F(1.4, 21.1) = 7.11$, $P < 0.01$	condition x site effect $F(1.2, 17.7) = 15.14$, $P = 0.001$	condition x site effect $F(1.3, 20) = 31.55$, $P < 0.001$	condition x site effect $F(1.3, 19.4) = 28.46$, $P < 0.001$
HM vs. CR	condition x site effect $F(1.1, 16.6) = 6.48$, $P < 0.025$	condition x site effect $F(1.2, 17.9) = 6.51$, $P < 0.025$	condition x site effect $F(1.3, 19.1) = 17.86$, $P < 0.001$	condition x site effect $F(1.2, 17.8) = 14.25$, $P = 0.001$

* Effect approaches significance.

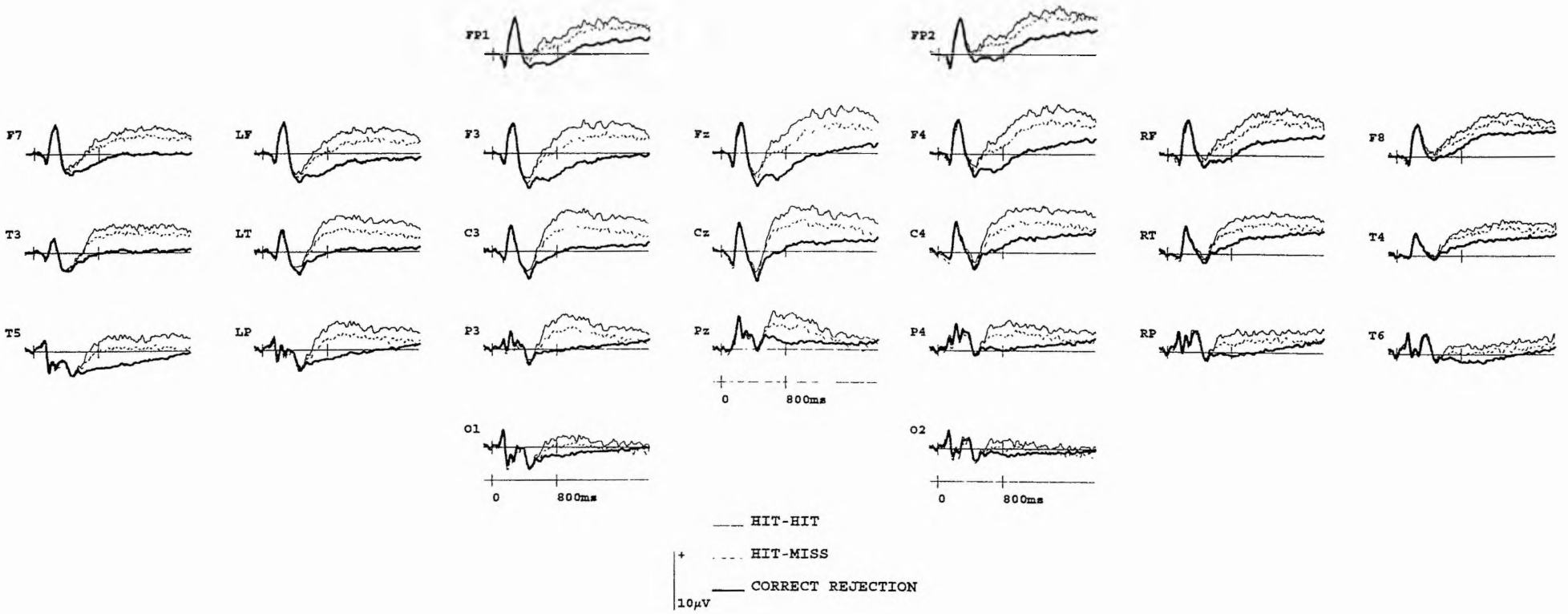


Figure 10.1 Grand average ERPs evoked by stems correctly completed with studied items, correctly or incorrectly assigned to study list (hit-hit and hit-miss ERPs, respectively), along with those evoked by stems completed with correctly rejected unstudied items (correct rejection ERPs). ERPs are shown for all 25 electrode sites (see figure 4.1 legend for description of the site labels).

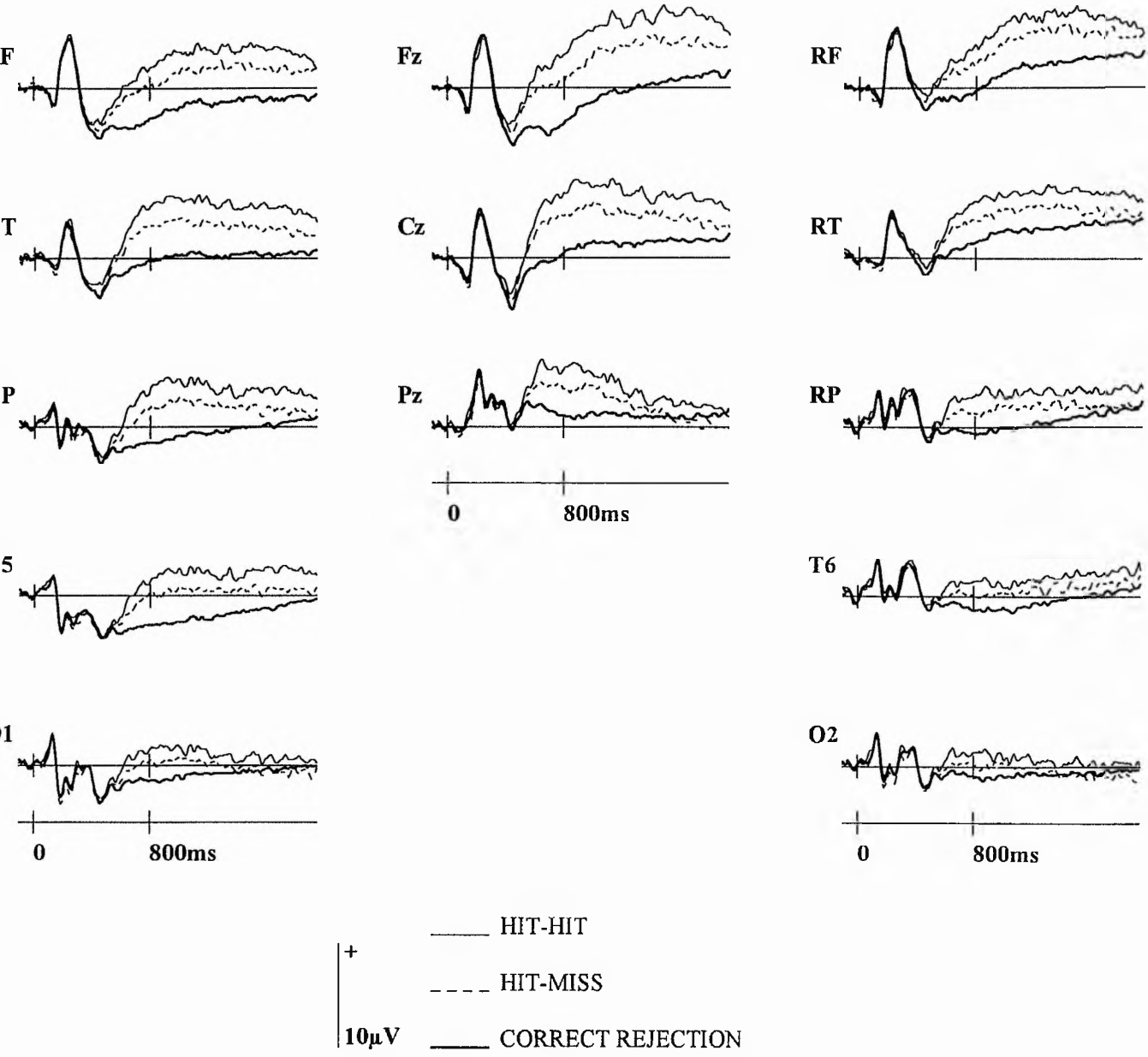


Figure 10.2 Grand average ERPs evoked by hit-hit, hit-miss and correct rejection ERPs. See figure 4.2 legend for description of the site labels.

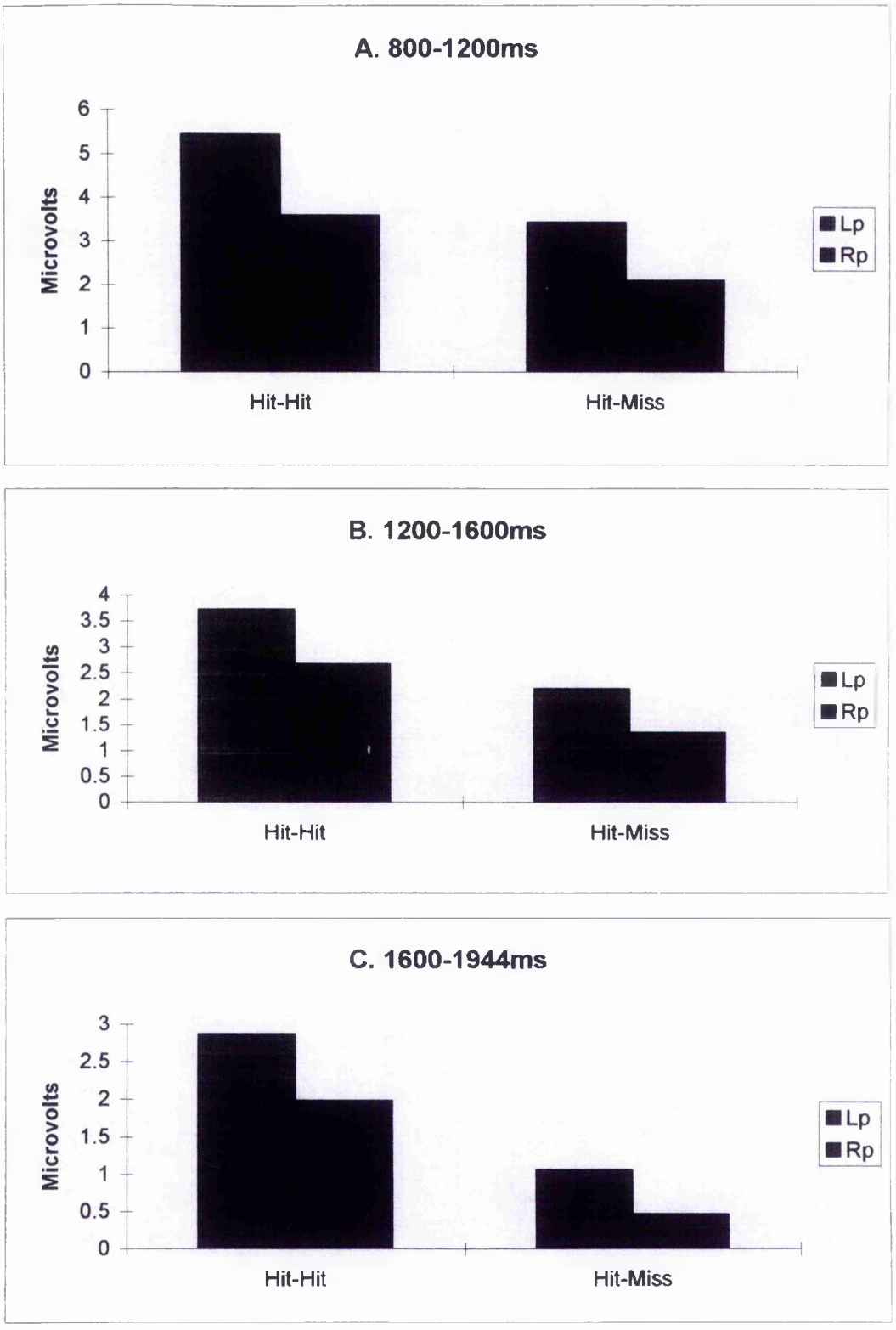


Figure 10.3 Mean amplitudes of the difference between the correct rejection ERPs and the hit-hit and hit-miss ERPs at the left (Lp) and right (Rp) parietal electrode sites. Shown separately for the a) 800-1200ms, b) 1200-1600ms and c) 1600-1944ms latency regions.

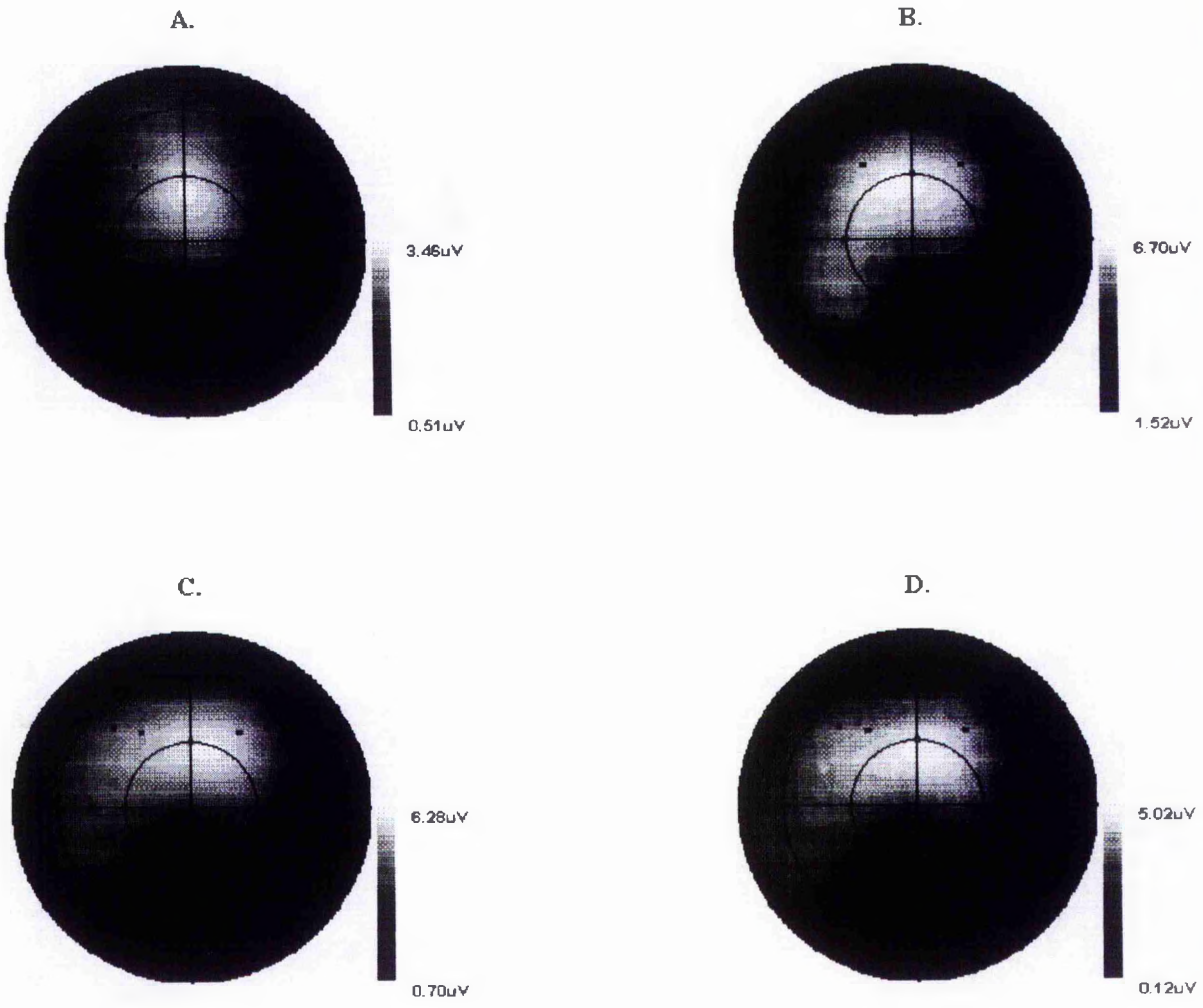


Figure 10.4 Topographic voltage maps for the hit-hit ERP effect (formed by subtracting the correct rejection ERPs from the hit-hit ERPs). The figure represents the relative amplitude of the differences between hit and correct rejection ERPs over the (a) 400-700ms, (b) 800-1200ms, (c) 1200-1600ms and (d) 1600-1944ms latency regions, incorporating data from all 25 electrode sites. The scale bar to the right of each map indicates the mean maximum and minimum values of the magnitude of the old/new effect across all electrode sites during the selected latency regions.

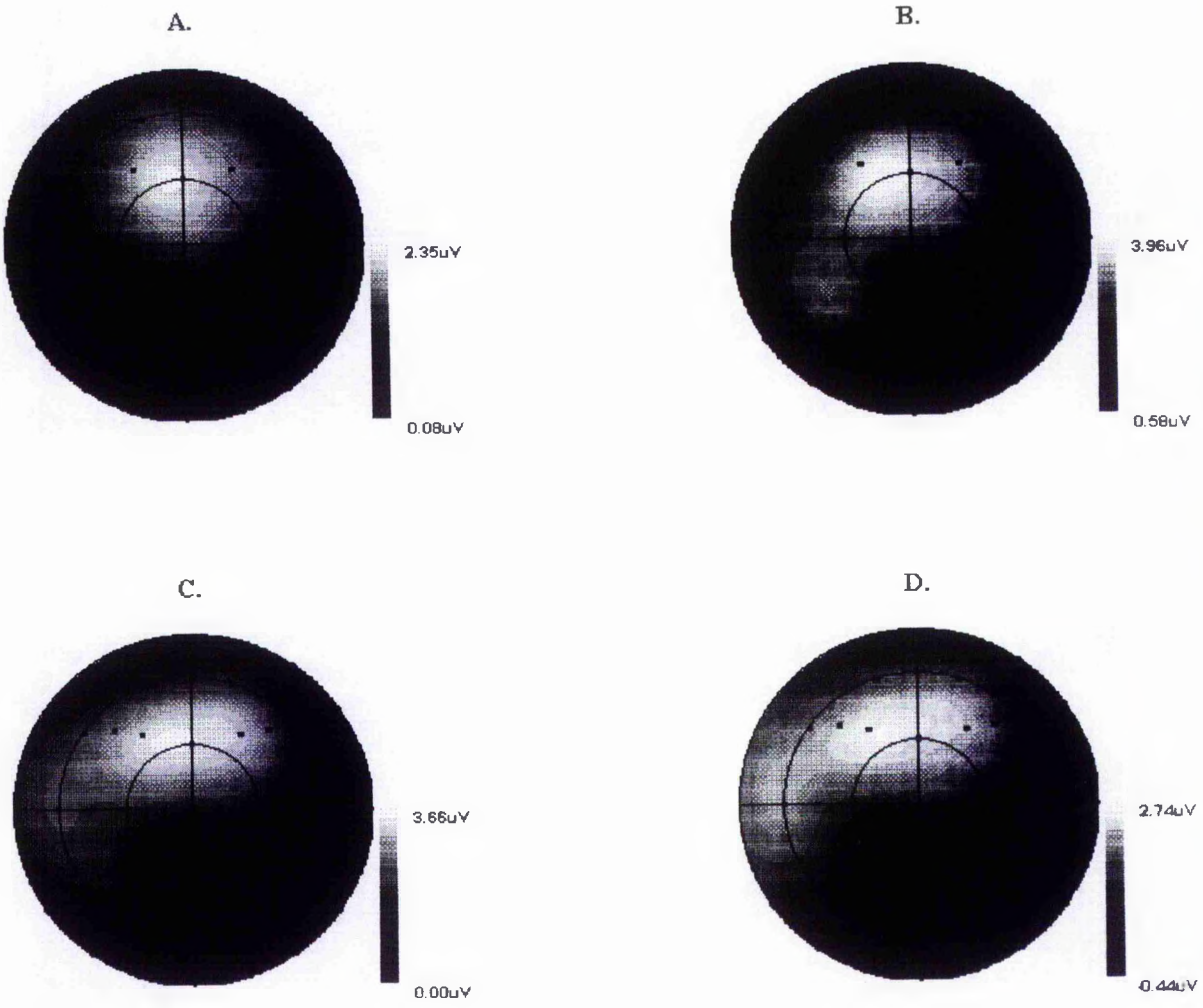
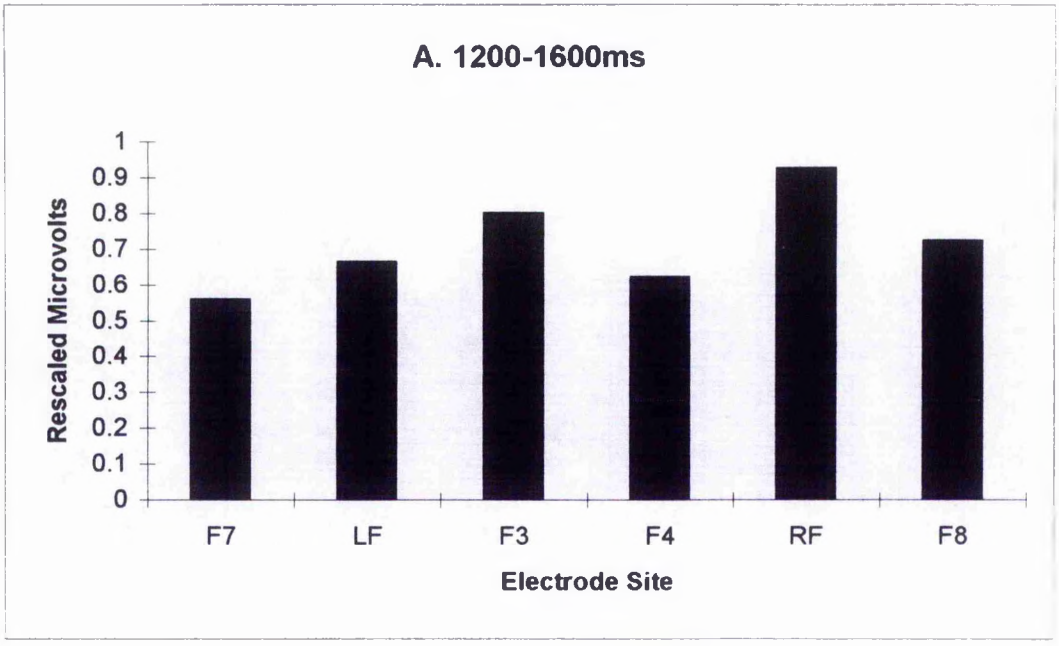


Figure 10.5 Topographic voltage maps for the hit-miss effect (formed by subtracting the correct rejection ERPs from the hit-miss ERPs). Latency regions, and scale bar, are as for figure 10.4.



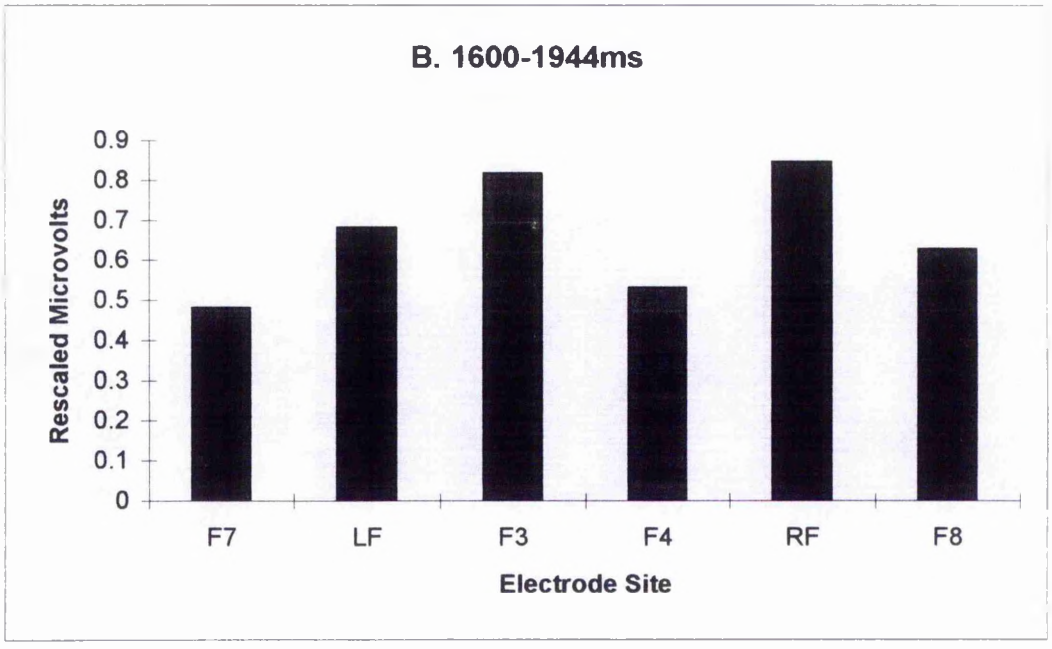


Figure 10.6 Rescaled mean amplitudes for the difference between the hit-hit and correct rejection ERPs (hit-hit effect) at the lateral anterior electrode sites during the a) 1200-1600ms and b) 1600-1944ms latency regions.

11.0 General Discussion and Conclusions

The major substantive issues raised by the behavioural and ERP findings from each study were dealt with fully in the discussion sections for each experiment. In this general discussion chapter I will therefore only review the findings of each study, to illustrate how they relate more generally to the study of memory, and to the issues raised initially in chapter 1 on which the present studies were based. This review will also highlight the progression in understanding of the cued recall and recognition memory ERP effects which has developed over the course of the investigations.

The six experiments presented in this thesis fall naturally into three parts. In the first part (experiments 1, 2 and 3), ERP correlates of explicit retrieval on cued recall and stem completion were identified [9]. In the second part (experiments 4 and 5) the ERP correlates of explicit retrieval on cued recall and recognition memory were contrasted. In the third and final part a single study was presented which further investigated the functional nature of the processes contributing to the cued recall ERP effect. The results of these six studies are summarised briefly below.

The ERP correlate of explicit retrieval on cued recall is composed of at least two spatiotemporally overlapping components. One component, the 'left parietal old/new effect', has been observed on a number of other direct (e.g. recognition memory) and indirect tests of memory (see chapter 3). The other component, the 'frontal effect', is similar to the 'right frontal old/new effect' also observed in previous studies of direct tasks, including recognition memory. The frontal effect for cued recall differs from the right frontal old/new effect mainly in terms of the degree of hemispheric asymmetry which it exhibits. The asymmetry of the right frontal old/new effect, as its name suggests, is more pronounced. The ERP correlates of explicit retrieval on

[9] The results of experiment 2 are not discussed below because of the item selection bias which afflicts the interpretation of the observed ERP effects (see chapter 6/7).

tests of cued recall and recognition memory are thus highly similar, though some differences are evident. In particular, the distribution of the right frontal old/new effect is much more restricted to anterior electrode sites than is the frontal cued recall effect. This difference may indicate the contribution of brain regions to cued recall which do not contribute to recognition memory. Alternatively, this difference may reflect nothing other than the more complete overlap of the two components on cued recall than recognition memory. Thus, towards the end of the recording epoch, the left parietal component for recognition memory is no longer active, whereas for cued recall this effect both onsets later, and also may last longer.

11.1 Explicit and Implicit Retrieval on the Cued Recall Task

In each study involving the cued recall task, ERPs evoked by stems attracting the explicit retrieval of studied items were contrasted with those evoked by stems attracting completion with unstudied items. In experiment 1, this contrast revealed a sustained frontally maximal positive-going modulation associated with explicit retrieval (e.g. figure 5.3). This positive-going modulation, termed the 'cued recall ERP effect', was symmetrically distributed about the scalp midline. The distribution of this effect over the scalp did not appear to be sensitive to a depth of processing study manipulation, and since experiment 1 employed only 13 electrode sites, topographical analyses of the scalp distribution of the cued recall effect were not performed.

The ERP data from experiment 1 allowed two alternative explanations of the cued recall ERP effect to be ruled out. First, this effect may have reflected the nature of the recognition decision ('old' as opposed to 'new'), employed as an operational measure of explicit memory, rather than memory for old items. However, *false alarm* ERPs (for stems completed with unstudied items which were incorrectly judged as 'old') did not show the cued recall ERP effect (figure 5.2). Second, the cued recall ERP effect could have reflected processes mediating implicit retrieval of studied items. However, *miss* ERPs (for stems correctly completed with

unrecognised studied items) also did not show the cued recall ERP Effect (figure 5.4). These critical findings indicate that neither an 'old' judgement nor implicit retrieval is a sufficient condition for the cued recall ERP effect. The results of experiment 1 therefore indicate that the cued recall ERP effect reflects neural activity associated with the explicit retrieval of studied items.

No evidence was found for an ERP effect reflecting the implicit retrieval of studied items in experiment 1. This conclusion follows from the finding (figure 5.4) that the effect is apparently absent when evoked by misses (implicit retrieval, stems correctly completed but unrecognised). My contention was that the 'miss' condition provides a 'pure' measure of implicit retrieval, since by definition miss responses are not associated with explicit memory. Since there was no ERP effect of implicit retrieval, this might, mistakenly, be taken to indicate that cued recall is a pure measure of explicit retrieval. This conclusion would be wrong for two reasons. First, it may be that processes mediating implicit retrieval on this task either are significantly attenuated, or simply do not give rise to detectable scalp ERP correlates.

Second, and more importantly, the cued recall ERP effect varied in magnitude (figure 5.1) according to the proportion of trials associated with positive recognition judgments (89% for the semantically studied items vs 55% for non-semantically studied). This indicates that the effect reflects explicit retrieval. It also strongly indicates that correct completions on this task are retrieved both implicitly and explicitly. The depth of processing manipulation thus affected both the overall number of correct completions (semantically studied: 42.3%; nonsemantically studied: 35.3%), and also the proportion of these which were explicitly retrieved. This is an important aspect of the data from experiment 1, since it emphasises that direct task instructions *must* take into account the possibility that a proportion of correct completions will be made on the basis of implicit and not explicit retrieval. For example, if the cued recall instructions require only that correct completions be retrieved, then the resulting 'recall' rate will reflect a mixture of implicit and explicit retrieval processes. The simple expedient of taking the subjects' state of awareness

into account affords a more pure (and therefore sensitive) measure of explicit retrieval.

11.2 Involuntary Explicit Retrieval on the Stem Completion Task

Experiment 3 investigated ERP correlates of stem completion. A positive-going ERP modulation was also observed on this task. This effect occurred in ERPs evoked by stems completed with items accorded deep study, relative to ERPs evoked by stems completed with shallowly studied items and unstudied items, which did not differ from one another in this respect (figure 7.2). In contrast, behavioural priming did not vary as a function of the depth of processing study manipulation. This indicates that subjects did not adopt an intentional retrieval strategy on the task, since if they had done so, a depth of processing effect would have been observed, as was the case for the behavioural data from the cued recall task in experiment 1. Accordingly, if it is accepted that the ERP effect observed for deeply studied items reflects explicit retrieval, then this retrieval was involuntary. This involuntary explicit memory was affected by the depth of processing manipulation, since the effect was absent for stems completed with shallowly studied items.

These findings are consistent, in two critical respects, with those reported by Richardson-Klavehn, Schacter et al. reviewed in Chapter 1, employing off-line and on-line behavioural measures of awareness (Bowers and Schacter, 1990; Java, 1994; Richardson-Klavehn, Gardiner and Java, 1994; 1996; Richardson-Klavehn and Gardiner, 1995; 1996; see also Richardson-Klavehn et al., 1994; Schacter, Bowers and Booker, 1989). First, the present ERP data suggest that significant levels of priming for shallowly studied items can occur in the absence of appreciable levels of explicit memory. Second, the present ERP data suggest that explicit memory occurs more frequently for items accorded deep than shallow study.

The ERP effect observed for stem completion was much weaker in magnitude than the effect observed for cued recall. Indeed, the stem completion effect was only

statistically reliable at midline sites during the 400-900ms period. Because of the weakness of this effect it is not clear exactly how it differs from the cued recall ERP effect observed in experiment 1. However the ERP effects from each task are qualitatively similar (contrast figures 5.1 and 7.2). Bearing in mind the need to replicate the stem completion effect to assess its reliability, it is nevertheless possible that the ERP effects for stem completion and cued recall reflect similar neural processes. These processes are therefore not qualitatively affected by the nature of the retrieval strategy employed by subjects (intentional vs. incidental).

The present findings for stem completion are analogous to those in other ERP studies of indirect tasks. As reviewed in Chapter 3, in ERP studies of perceptual identification and lexical decision, old/new ERP effects have been observed which appear to resemble ERP effects observed on tests of recognition memory (Paller and Kutas, 1992; Paller, Kutas and McIssac, 1996). The old/new effects observed on these studies have been interpreted as reflecting involuntary explicit memory (Paller and Kutas, 1992; Paller, Kutas and McIssac, 1995). Thus, a number of sources of evidence point to the conclusion that positive-going ERP modulations on tests of memory are not dependent upon an intentional effort to retrieve. These findings suggest that the neural activity reflected by the ERP effects cannot be associated with processing associated with an intention to retrieve. Rather, the ERP effects may reflect the outcome of successful retrieval, expressed as explicit memory.

11.3 An ERP Correlate of Implicit Retrieval on Stem Completion?

A modulation of the P2 ERP component was also observed in experiment 3 (see figure 7.2). This P2 effect was sensitive to the depth of processing manipulation, since the P2 was smallest for ERPs evoked by stems completed with shallowly studied items over left anterior sites, relative to those evoked by stems completed with deeply studied or unstudied items. The P2 and later positivity discussed above appeared to have different distributions over the scalp. This is at least consistent with my suggestion that the P2 may reflect processes unrelated to explicit retrieval. The

P2 effect was therefore tentatively linked with implicit retrieval processes possibly involved with the facilitation or transfer of conceptual / semantic processing from study to test presentations. This effect is not discussed further, though it warrants replication and if found to be a reliable phenomenon deserves further attention and investigation. One interesting experiment would be to contrast the effects of changes in study / test modality on the P2 and later positivity. If each effect reflects processes independent of priming based on perceptual features of study and test items, then this modality manipulation should have little effect on the P2 and the late positivity. A similar study of cued recall would also be interesting, as another means of investigating the nature of the explicit retrieval processes contributing to the cued recall effect.

11.4 Explicit Retrieval on Tests of Recognition Memory and Cued Recall

In experiments 4 and 5 ERP correlates of explicit retrieval on the cued recall and recognition memory tasks were compared. Each study employed a more dense electrode montage to allow a relatively fine-grained contrast between the scalp topographies of the ERP effects observed for each task. In experiment 4 an overt recognition decision following each completion once more allowed ERPs to be formed for stems completed with explicitly retrieved studied items. However in this study the response requirements were altered so that recognitions decision were made using a button press, rather than verbally as in experiment 1. In addition, the time allowed subjects to prepare a response was shortened to 2s in this study, compared to the 3s period given in experiment 1.

11.4.1 Multiple Components of the Recognition Memory ERP Effect

In experiment 4 an asymmetrical parietally distributed positive-going ERP effect was observed in *hit* ERPs (for correctly recognised old items) relative to *correct rejection* ERPs (for correctly rejected new items) (hereafter termed the 'left parietal old/new effect'). As reviewed in Chapter 3, numerous other ERP studies of

recognition memory have also reported left parietal old/new effects. Such effects are interpreted as reflecting explicit retrieval processes providing information sufficient for correct old/new judgments.

A more sustained and anteriorly distributed positive-going modulation was also present in hit ERPs on the recognition memory task. This effect appeared to predominate to the right of the midline (figure 8.6). This finding is the first report of a 'right frontal old/new effect' on a test of item recognition. That is, a recognition test which does not include an overt requirement to give either source judgments (e.g. Wilding and Rugg, 1996) or to make associative recognition judgments (Donaldson and Rugg, submitted). As discussed in chapter 3, the interpretation of right frontal old/new effects observed on tests of source memory and associative recognition is not entirely clear. It appears though that the effect may be a correlate of processes, possibly instantiated within the frontal lobes, which act to cohere or to integrate disparate retrieved fragments of a study episode into an explicit representation (Moscovitch, 1994; and see chapter 1).

Chapter 3 introduced the findings of a number of studies which require that this interpretation of the frontal effect be refined. In particular, the findings of Donaldson and Rugg's (submitted) study of word-pair associative recognition are difficult for any proposal which links the right frontal effect with the deployment of specific post-retrieval processing as a strategic voluntarily controlled response to the demands of a source memory task, as Wilding and Rugg (1996; in press; submitted) suggest. Briefly, Donaldson and Rugg (experiment 2) showed that the right frontal old/new effect ocurred in hit ERPs on a test of recognition memory for word-pairs (e.g. PENCIL-TABLE). This study only required an old/new judgment, and did not require subjects to make source judgments, or to overtly engage in any form of 'post-retrieval' processing. In their experiment 1, they also showed that a right frontal old/new effect occurred when subjects were required to judge if the test stimuli (word-pairs) were in the same or a rearranged pairing as at study. The right frontal old/new effect thus occurred irrespective of whether an additional judgment, beyond a recognition (old/new) judgment, was required. This suggests that the effect

is related more to processes concerned with the associative recognition judgment, than to any requirement for a further discrimination. Therefore the processes reflected by the right frontal effect cannot depend on a task-specific demand to make further discriminations on information retrieved from long-term memory.

The presence of right frontal effects in the present experiment 4 provides further strong evidence that the processing reflected by this ERP effect is not contingent upon an overt task requirement to make any form of source or 'post-retrieval' judgment. The processes reflected by the right frontal effect are therefore not engaged in response to a specific task demand to retrieve source information or indeed anything associated specifically with source memory at all. The effect may therefore reflect a rather more general property of retrieval processing on certain tests of memory. This notion is supported also by the ERP findings from the cued recall tasks in experiments 4 and 5, which are discussed below.

11.4.2 Multiple Components of the Cued Recall ERP Effect

Under the conditions of experiment 4, the cued recall ERP effect had a more posterior and asymmetrical (left greater than right) scalp distribution. The topography of the left parietal old/new effect observed on the recognition task in experiment 4 was identical to the cued recall ERP effect during the latency region in which the cued recall effect occurred (800-1100ms). The finding of essentially identical parietal ERP effects on the cued recall and recognition tasks thus indicates similarity in the retrieval processes engaged by each task, despite the differences in retrieval cues as a function of task (stems vs. whole word 'copy cues'). The only difference in the left parietal effects observed on each task was that for recognition the effect onset nearly 700ms earlier (346ms vs. 1014ms). This may indicate a difference in the relative timing of retrieval processing on each task, with cued recall being delayed with respect to recognition memory.

This convergence in the ERP findings from both tasks supports the contention that similar processes mediate performance in each case. Recent attempts to incorporate recollection within dual-process models of recognition memory and cued recall (Jacoby and Hollingshead, 1989; Jacoby, Toth and Yonelinas, 1993; Lindsay and Kelley, 1996) thus receive support from the present studies. However, the present ERP findings contribute independent electrophysiological evidence on the time course and scalp topography of neural activity associated with recollection on tests of cued recall. The topographical data are particularly important, since they provide one basis for a crude definition of the brain regions contributing to recollection on this task. The ERP effects thus provide a template, or marker, for the activity of these regions during task performance. This marker also appears on tests of recognition memory, indicating that similar brain regions may contribute to recollection on cued recall and recognition memory.

The distribution of the parietal old/new effect observed for cued recall in experiment 4 contrasted markedly with the distribution of the cued recall ERP effect observed in experiment 1. In experiment 1 the cued recall ERP effect appeared to have a more symmetrical and anterior distribution (figure 5.1), while in experiment 4 the cued recall ERP effect was asymmetrical and largest over the posterior parietal electrode sites (figure 8.4). These different effects indicate that qualitatively different patterns of brain activity were engaged in each case.

The interpretation given to these disparate findings was that the cued recall ERP effect may be composed of at least two 'components' which partially overlap spatially and temporally. One component is reflected by the left parietal positivity observed in isolation in experiment 4. The other component may be more symmetrically distributed, or right>left, and maximal over the anterior electrode sites. The more anterior component and the parietal component may have both been present in experiment 1, but the spatiotemporal summation of their activity may have resulted in an inability to distinguish them. If correct, this account suggests that the two components also differ in terms of their time course, since in experiment 4 the onset latency of the parietal effect was around 1s, and persisted for around 300ms,

whereas in experiment 1 the cued recall ERP effect onset around 300ms and persisted for over 1s. Thus, the frontal component may onset earlier, and possibly persist for longer, than the parietal component.

In the discussion for experiment 4 I suggested that the response methodology may have discouraged, reduced or eliminated post-retrieval processing of information on the cued recall task, possibly due to pressure of time constraints because only 2s were allowed for response preparation. The onset latency of the parietal effect for cued recall in this study supports the argument. The onset latency was 1014ms, which only leaves 1s or so for 'post-retrieval' processing to commence. In contrast, retrieval processing for recognition memory, as indicated by the onset latency of the left parietal effect for that task, was 346ms. Another possibility discussed was that the time constraints in conjunction with the response method (button pressing) may have encouraged a different cued recall strategy on this task. The strategy may have been to respond 'old' if the stem was recognised as having belonged to a studied item, without actually retrieving the studied item itself. This alteration in response methdology, leading to increased time pressure and the possibility of variable task strategies may have eliminated the contribution of processes reflected by the frontal component of the cued recall ERP effect.

The aim of experiment 5 was therefore to elicit the more frontally distributed component of the cued recall ERP effect, employing the response methodology used in experiment 1, in order to determine whether similar frontally distributed ERP effects could be observed for cued recall and recognition memory. Under these conditions, where responses were given verbally and subjects had 3s for response preparation, the recognition memory ERP data replicated the findings of the previous experiment 4. This finding underlines the points made previously concerning the necessary and sufficient conditions for the right frontal old/new effect.

A clear left parietal component of the cued recall ERP effect could not be observed in experiment 5. This may have resulted from the spatiotemporal summation of the activity generated by the parietal and frontal components which I suggested

contribute to the cued recall ERP effects. This is supported by the finding that a more anteriorly distributed component of the cued recall effect was observed, as predicted, in this study. The suggestion that multiple components contribute to the cued recall ERP effects had so far been based on the joint findings of experiments 1, 3, and 4. But in experiment 5 the more anterior component of the cued recall effect was identified, and its distribution at anterior sites during early (400-1200ms) and late (1200-1944ms) portions of the recording epoch was analysed.

During the early period, at anterior sites the cued recall ERP effect was symmetrically distributed about the scalp midline. However, during the later 1200-1944ms period the cued recall effect was maximal on and just to the right of the scalp midline (see figure 9.6b). Though the cued recall effect extended more posteriorly than the right frontal old/new effect for recognition memory, the co-occurrence of right anterior maxima on the cued recall and the recognition memory tasks suggests that each task engaged similar processes. Thus the processes reflected by the right frontal old/new efffect may also make some contribution to cued recall. This conclusion received strong support from the results of experiment 6, which employed a new operational measure of recollection to investigate the functional nature of the (multiple) processes contributing to the cued recall ERP effect.

11.5 Cued Recall with and without Retrieval of Source

In experiment 6, the operational measure of recollection involved asking subjects to judge the temporal context in which studied items were presented. Once more, retrieval was cued by word-stems, and following completion with studied items subjects had to say in which of the two study lists each item was presented. The main finding from the study was that left parietal and the frontal components of the cued recall effect were now both evident (figures 10.4 and 10.5). The study thus strongly supports the hypothesis that the cued recall ERP effect is composed of multiple components.

By requiring subjects to make source judgments for the temporal context in which studied items were presented, experiment 6 allowed ERPs to be contrasted as a function of the success of this discrimination. Importantly, ERPs were formed for items which the subjects recognised as studied, but for which source could and could not be retrieved (hit-hit vs. hit-miss ERPs, respectively). The two components of the cued recall ERP effect, the left parietal and the frontal effect, were present in both the hit-hit and hit-miss ERPs. As in experiment 5, the frontal effect was initially symmetrical and then subsequently became focused on and just to the right of the scalp midline. Thus once again the frontal effect observed for cued recall exhibited a slight right>left asymmetry, qualitatively similar to the right frontal old/new effects for recognition memory.

The only difference between hit-hit and hit-miss ERPs was that the amplitude of each component was greater for hit-hit than hit-miss ERPs. A number of previous studies have already shown that the magnitude of the parietal effect appears to be sensitive to the amount or quality of retrieved information (e.g. Donaldson and Rugg, submitted; Rugg et al., 1995; Tendolkar and Rugg, submitted; Wilding and Rugg, 1996; and see Smith, 1993). The present findings are consistent with this proposal. Thus, in the condition where accurate temporal context judgments were made (hit-hits) a larger parietal effect was observed. This may indicate, as argued in chapter 10, that the ability to make a correct source judgment is correlated with the retrieval of more information from the study episode.

The magnitude of the frontal cued recall effect was also sensitive to the success of the source judgment. Wilding and Rugg (1996) reported similar findings for the right frontal old/new effect observed in their study of source memory for gender of speaker voice at study. Thus, in addition to the similarity in scalp distribution and time course, the frontal effects for cued recall and source memory appear to show similar changes as a function of experimental manipulations of recollection. This provides further support for the notion that on each task the frontal effects reflect similar cognitive processes.

11.6 A Third Component of the ERP Effects?

Experiment 6 also provided some evidence that the initial portion of the frontal effect (from 400-1200ms or so) was more symmetrically distributed than the later portion. Similar findings were reported in experiment 5, where from 400-1200ms at frontal electrodes there was no evidence for a right>left asymmetry. These findings are also supported by the results of experiment 1, in which the cued recall effect recorded from 400-1434ms post-stimulus also did not show any sign of a frontal asymmetry. The critical contribution of experiment 6, however, was to show that the initial portion of the frontal effect from 400-700ms was reliably present prior to the onset of the parietal asymmetry characterising the left parietal effect. This indicates that the early symmetrical frontal effect is not merely a consequence of the summation of a left parietal effect and a slightly asymmetrical frontal effect, resulting in a symmetrical frontal effect [10]. Instead, the early portion of the frontal effect may reflect a component distinct from either the left parietal component or a later more asymmetrical frontal component.

A common finding from previous studies of source memory and associative recognition is that the right frontal old/new effect onsets later than the left parietal effect [11]. However, in each study the actual onset latency of positive-shifts in the relevant ERPs is earliest at the more anterior electrode sites (Donaldson and Rugg, submitted; Wilding and Rugg, 1996; Wilding and Rugg, submitted). From onset until around 1100ms post-stimulus, at anterior sites the positive-shift is typically symmetrical in distribution. It is not until after 1100ms or so that the right>left asymmetry develops. Thus these previous studies also provide some support for the notion that the early and late parts of the frontal effect may reflect separable

[10] This conclusion is qualified by the possibility that the asymmetry of the left parietal effect may take some time to develop after the processes reflected by the effect have onset. This means that prior to the onset of the asymmetry (circa 700-800ms), the anterior propagation of the activity of the generators of the parietal component could give rise to positivity which is symmetrical at the anterior electrodes.

[11] The exclusion paper reported by Wilding and Rugg (in press) is an exception, for in this study the right > left frontal asymmetry was present practically from the onset of the positive shift at frontal electrode sites. Reasons for this are not clear.

components, on the grounds of their scalp distribution. Further study will show whether the 'two' components of the frontal effects reflect different aspects of cognitive processing relevant to the task in hand.

11.7 Neural Generators of the ERP Effects

The topographical analyses employed in the studies presented in this thesis were used to determine whether ERP effects differed qualitatively. Such qualitative differences provide a basis for concluding that each ERP effect reflects functionally distinct processes (see chapter 2). The topographical analyses were also employed to show whether a given ERP effect itself changed distribution over time (e.g. from a left parietal to a right frontal maxima). Again, the point of this was to show whether over time qualitatively different patterns of brain activity, and hence different cognitive processes, contribute to a given ERP effect.

For experiments 4, 5 and 6, the topographical analyses showed the manner in which the cued recall and recognition memory ERP effects varied as a function of task and also over time. As noted above, these analyses led to the hypothesis that multiple components contribute to the effects observed on each task. However, the topographical analyses do not allow any conclusions to be made as to the location of the generators of the components of the ERP effects. This is because of the 'inverse problem', which states that a unique solution for the location of intracerebral generators cannot be derived from scalp-recorded ERP data alone. In order to determine the location of the generators of the ERP effects other sources of evidence must be considered.

Data from intracranial and scalp ERP recordings from neuropsychological patient groups have already been discussed in chapter 3. These studies indicate that the medial temporal lobes may play a role in the generation of the parietal old/new effect. In the section below, data from functional imaging studies of memory is

introduced which suggests that regions of prefrontal cortex may play a role in performance on tests of cued recall and recognition memory.

11.7.1 PET Studies of Explicit Retrieval

A number of recent functional imaging (positron emission tomography, or PET) studies of recognition memory, cued recall and stem completion have been carried out (e.g. Buckner et al., 1995; Kapur et al., 1994; Nyberg et al., 1995; 1996; Rugg et al., in press(a); Schacter et al., 1996; Tulving et al., 1994; for reviews see Buckner and Tulving, 1995, McCarthy, 1995 and Ungerleider, 1995; and see chapter 1). These studies have employed the PET technique to identify brain regions specifically engaged during performance on these tasks (as measured by localised changes in regional cerebral blood flow). The relationship between the activated regions identified in these studies, and the generators of the ERP effects discussed above is completely unknown at the moment. Attempts to relate the findings of the two techniques should therefore be treated with some caution. In the brief discussion to follow, the main findings of these PET studies are summarised, as are the current interpretations given to these findings, so as to draw out some points of contact which may exist between the ERP and PET results.

Discussion of the PET findings has focused on three 'sets' of activated regions. The first concerns activation of the left and right hippocampal formation, which, as already noted in chapter 1 of this thesis, can in the case of the right activations depend upon maintaining feature overlap between study and test presentations of stimuli (Buckner et al., 1995). The second set of findings concerns decreases in activation within posterior occipital cortex, particularily on the right, which again have already been discussed in chapter 1. These findings have been associated with the facilitated processing of visual perceptual features of stimuli at test; i.e. priming on tests of stem completion, and possibly the explicit retrieval of such features on tests of cued recall (see chapter 1 for more detail). The final set of findings concerns activations of left and right dorsolateral prefrontal cortex. These activations have not as yet been discussed in the thesis.

It is tempting (and parsimonious) to speculate that the frontally distributed ERP effects discussed above may be the electrophysiological correlate of the prefrontal regions activated in these PET studies. While there is no direct evidence to support this claim, the functional interpretations which the PET researchers have given to the prefrontal activations may benefit from some aspects of the ERP findings, and vice versa. The prefrontal PET activations are variously interpreted as reflecting processes specific to retrieval effort per se (e.g. Kapur et al., 1994), to retrieval effort and also retrieval success (e.g. Rugg et al., in press(a)), or to processes mediating a change in retrieval mode from semantic / lexical memory to episodic memory, depending upon task demands (Buckner et al., 1995; Schacter et al., 1996).

Buckner and Tulving (1995) have summarised the results of a number of studies of explicit retrieval, and produced a 'Hemispheric Encoding Retrieval Asymmetry (HERA) model of prefrontal involvement in the encoding and retrieval of information specific to episodes (Tulving et al., 1994). According to this model, right prefrontal cortex is involved in retrieval from episodic memory. This hypothesis was slightly refined by Nyberg et al. (1995), by the suggestion that regions of right prefrontal cortex play some role in maintaining an episodic retrieval 'mode', and that the activity of such regions does not reflect successful retrieval per se, which Nyberg et al. (1995) suggest involves other regions of cortex which actually store episodic memory traces. This account predicts that the activity of prefrontal regions should *not* be modulated according to whether episodic retrieval is successful.

This prediction receives some support from a PET study of recognition memory carried out by Kapur et al. (1994). Kapur et al. contrasted PET activations in conditions where subjects were presented with lists of words containing either a low or a high proportion of old (studied) words. Significant increases in the activity of right prefrontal cortex were observed on the recognition task for both low and high 'target' density lists, but activity within right prefrontal cortex did not differ as a function of increasing the proportion of old items. This finding was ascribed to the

role of such regions in a 'retrieval mode', distinct from retrieval per se, which Kapur et al. argued would have been significantly affected by increasing the proportion of old items. Schacter et al. (1996) drew the same conclusion with regard to the role of right prefrontal cortex during the word-stem cued recall task. However, the findings of a recent study by Rugg et al. (in press(a)) suggest that the right prefrontal cortex is affected by retrieval success, and so the function of this region may not just relate to a 'retrieval mode'.

Rugg et al. (in press(a)) contrasted PET activations in zero (i.e. all new), low and high target density conditions on a test of recognition memory. They found that the activity of right prefrontal cortex distinguished between the zero target and both the target present conditions. In contrast, activity within the right prefrontal cortex did not distinguish between the low and high target density conditions. Rugg et al. thus replicated the results of Kapur et al. (1994), for the contrast between low and high target density conditions, but Rugg et al. also showed that the activity of the right prefrontal cortex *did* distinguish between zero and target present conditions, which Kapur et al. could not show because of their experimental design. In conclusion, these results were interpreted as reflecting the sensitivity to retrieval success of processes carried out by right prefrontal cortex.

These PET data relate to the ERP effects discussed above because the frontal distribution of the ERP effects is consistent with the notion that regions of prefrontal cortex, and possibly right more than left, are differentially active according to the success of episodic retrieval. This is shown by the results of Wilding and Rugg's (1996) study of source memory, in which the right frontal effect was larger when retrieval of source was correct than incorrect, and is also shown by the findings of experiment 6, where the frontal cued recall effect was larger when accurate temporal context judgments were made. Further study is needed to allow more detailed and firmer conclusions to be made regarding the relationship between the ERP and PET findings, though as noted, some parallels are already evident.

11.8 Future Studies of the Parietal and Frontal ERP Effects

11.8.1 The Parietal ERP Effect

There is a particular need for studies contrasting ERP correlates of memory on direct and indirect tasks, to show whether or not performance on indirect tasks solely elicits parietal old/new effects. The present results from experiment 3 suggest that this is not the case, in so far as this study showed a sustained and frontally maximal ERP effect for stems completed with deeply studied items. Additional research is also necessary to better characterise the relationship between the processes reflected by the parietal and frontal effects. One immediate concern is how to reconcile the notion that the former effect reflects retrieval processing, while the latter reflects some aspect of post-retrieval processing, given that the early symmetrical frontal effect is if anything of shorter onset latency than the parietal effect. The processes reflected by the early frontal effect cannot therefore by contingent upon the successful outcome of processing reflected by the parietal effect (Tendolkar and Rugg, submitted; and see discussion below).

Further study of the parietal effect should obviously exploit the current functional interpretation of this effect, which suggests that it is somehow linked to explicit retrieval processing. Qualitative variation in the nature of explicitly retrieved information may be correlated with changes in the location of the brain regions activated during retrieval (e.g. Damasio, 1989a,b; Damasio and Damasio, 1994; Johnson and Chalfonte, 1994; Johnson, Kounios and Nolde, in press; Nyberg et al., 1995; Squire, 1992). This should give rise to qualitative differences in the scalp topography of ERP effects associated with such retrieval. Some preliminary evidence on this comes from a study by Schloerscheidt et al. (unpublished data; see also Friedman, 1990), where ERP correlates of old/new recognition memory were contrasted for words and for pictures of everyday objects (e.g. an apple). The study showed that in contrast to the above speculations, ERP effects related to explicit memory took the form of a left parietal old/new effect for each type of stimulus. This may suggest an important property of the processes reflected by the parietal old/new effect, for example that it is generated by regions involved more generally

with the explicit retrieval of different kinds of information. Alternatively, it may be that for each type of stimulus a similar kind of representation was the basis for explicit memory, despite changes in the nature of the materials.

It is also of interest to determine whether similar electrophysiological effects occur for explicit retrieval processes involving different brain regions. That is, given that explicit retrieval of different kinds of information is associated with ERP effects of qualitatively different topography, is it nonetheless true that the ERP effects in each case take the form of late positivities similar to the parietal effect? Such a finding would be extremely interesting since it would suggest that despite differences in the nature of the representations which are retrieved or re-activated, similar neurophysiological mechanisms are involved. If this is found to be the case, it could provide one means of systematically classifying explicit retrieval mechanisms based on their electrophysiological properties as measured by ERPs.

11.8.2 The Frontal ERP Effects

Recollection is a necessary but not a sufficient condition to elicit frontally distributed ERP effects on tests of cued recall or recognition memory. For cued recall, evidence for this came from experiment 4, where stems correctly judged as belonging to studied items elicited only a left parietal effect. For recognition memory, a number of findings point to this conclusion. To take just one, Rugg et al. (in press(b)), in their study of associative recall, showed that only a left parietal effect was elicited in conditions where subjects could accurately recollect studied words using words associatively paired at study with the to-be-retrieved item as retrieval cues. The frontal effects on cued recall and recognition also exhibit similar electrophysiological properties. Each effect is a sustained positive-going modulation with a very similar time course. Furthermore, the difference in the frontal ERP effects observed on each task is largely in terms of the *degree* of their hemispheric asymmetry (the asymmetry is more marked on tests of recognition memory).

In chapter 10 I discussed evidence from Tendolkar and Rugg's (submitted) study of recency memory, in which symmetrical frontal effects maximal at the fronto-polar leads were observed. Although the exact distribution of the frontal recency effect was altered with respect to that of the frontal effects for cued recall and recognition memory, in each case a sustained positive-going modulation of the ERP was observed. This indicates that processes associated with source memory, recency memory, recognition memory, cued recall and associative recognition (discussed above) may depend on similar neurophysiological mechanisms, possibly instantiated within different regions of the frontal lobes. This similarity occurs despite possible differences in the cognitive demands of each task. Nevertheless, based on these ERP data it is possible that a common kind of process is engaged by each task.

11.8.2.1 An Electrophysiological Correlate of Working Memory?

I have suggested one account of these frontal ERP effects, based on the notion that perhaps the most simple form of post-retrieval processing is simply to hold retrieved information in mind. This could plausibly have occurred in all of the experiments presented in this thesis, where there was always a delay interposed between stimulus onset and cue to respond (including the ERP study of stem completion). Under such conditions it is possible that post-retrieval processing could involve the maintainance, or 'monitoring', of retrieved episodic information. Petrides, Alivisatos and Evans (1995) have for example suggested that the on-line monitoring of information retrieved from long term memory may be an aspect of working memory. In the PET study of recognition memory carried out by Rugg et al (in press(a)), a similar suggestion was made as one possible account for the right prefrontal activations which were observed. A connection between working memory and prefrontal cortex has also been made by Goldman-Rakic and colleagues, based on their studies of single cell electrophysiology and lesions in primates (see Goldman-Rakic, 1987). In order to flesh out this idea, I will give a brief summary of a current view of working memory, based on the highly influential account given by Baddeley and colleagues (Baddeley, 1986, Baddeley and Hitch, 1974). While this brief summary does very little justice to the mass of empirical and theoretical work on

which it is based, it does provide a sufficient context in which to discuss the results of the present ERP studies.

Working memory is a general framework for studying cognitive processes which allow the conscious manipulation, in real-time, of limited amounts of information. Three aspects of working memory have been distinguished. First, capacity limited temporary storage buffers are postulated as the stores 'in which' information is actually held while it is manipulated. Different buffers have been proposed, and are themselves distinguished by virtue of the kind of information which each stores (e.g. verbal vs. spatial). Logically distinct from these buffers are the rehearsal / maintenance functions which allow information in the buffers to be maintained, or 'refreshed', over a period of time. Again, distinct rehearsal mechanisms have been proposed, each specific to the different buffers on which they operate. Distinct again is the 'central executive', viewed as a collection of control processes which act to coordinate behaviour in the service of the goals of a given task. It is quite commonly stated that the nature of the central executive is the least well understood of all components of working memory (Baddeley, 1996). Accordingly, Baddeley (1996) has recently proposed a number of research strategies which may give insight into central executive function. One strategy involves the study of the interaction between long term memory and working memory.

Petrides, Alivisatos and Evans (1995) and Rugg et al. (in press(a)) propose that prefrontal cortex may play some role in mediating interactions between episodic memory and working memory. The authors appear to suggest that these regions are involved either with the maintenance of retrieved episodic information, or with executive processes which allow retrieval to be monitored, to assess its relevance to the task in hand. Their suggestion is based on the finding, common to studies of long term memory and working memory, that regions of prefrontal cortex are activated during task performance (e.g. Buckner and Tulving, 1995). For example, PET studies indicate a particular role for left inferior prefrontal cortex in the maintainance of verbal information which is held in an anatomically distinct 'verbal working memory buffer', located within regions of left posterior parietal cortex (e.g. Paulesu,

Frith and Frackowiak, 1993; Smith, Jonides and Koeppe, 1996). Similar findings have been reported for spatial working memory (Jonides et al, 1993; Smith, Jonides and Koeppe, 1996; see also Smith et al., 1995). In this case, the rehearsal processes appear to involve regions of right prefrontal cortex, while the buffer itself may be located in right posterior parietal cortex.

Working memory for both verbal and spatial information may therefore involve an interaction between the prefrontal and parietal cortices. In general, it appears that working memory for different types of information may involve anatomically distinct regions of prefrontal cortex, instantiating rehearsal functions, and more posterior regions instantiating the short term capacity limited buffers in which information is held while being maintained (Goldman-Rakic, 1987). Rehearsal functions involve different regions of prefrontal cortex, and likewise the capacity limited short term buffers involve different regions of more posterior cortex. In order to rehearse or maintain different kinds of information 'simultaneously', it would therefore be necessary to coordinate the activity of a number of different regions of anterior and posterior cortex (Goldman-Rakic, 1987; Petrides, 1994).

It is not yet clear in what sense working memory may contribute to the monitoring or maintenance of explicitly retrieved episodic information. Put crudely, the above PET studies of working memory indicate that maintenance may involve as many interactions between regions of anterior and posterior cortex as there are different domains or types of information to be manipulated. This raises a puzzle over how episodic information may be maintained or monitored, since it is of the nature of recollection that it consists of the multi-modal content of previously experienced episodes (e.g. Baddeley, 1991; Damasio, 1989a,b; Damasio and Damasio, 1994). If such recollections are to be available to working memory, then apparently there is a need for a large number of different kinds of maintenance and buffer sub-systems, which can all work in concert to sustain recollection.

However, a more parsimonious account of working memory for episodic information may be given. It may be that regions of prefrontal cortex can interact directly with

the core medial temporal lobe memory system (see chapter 1), rather than with a number of modality or domain specific buffers, to bring about the online manipulation of retrieved episodic information. This account suggests that a prefrontal input to the medial temporal lobe system may act to modify the core system output, such that the multiple regions of cortex storing components of episodic memory are reactivated concurrently. Given that the prefrontal inputs to the core system can be sustained over time, then this may form a plausible basis for the *use* of the core system in the service of working memory. In particular, the prefrontal signal may provide a means of maintaining an explicit representation of a past episode over a period of seconds, during which time further operations, such as source discriminations, may be performed on the retrieved information.

The frontally distributed ERP effects may be an electrophysiological correlate of this interaction between working memory and explicit retrieval from long term memory. This account links the frontal ERP effects with processes which may mediate, under certain task conditions, the on-line generation of an explicit representation for retrieved information which may become available gradually over time. The gradual accumulation and incorporation of retrieved information 'into' such a representation is consistent with the temporal information for the frontal and parietal effects, which indicate that each is concurrently active. However, the sustained nature of the frontal effects is consistent with their hypothesised role in an ongoing process of maintenance or monitoring of retrieval products. Exactly how the processes reflected by the frontal effects may contribute to this function is not clear, and further research needs to be done to elucidate whether or not the present account is in any way correct.

One possibility for future study is to investigate the connection between frontal ERP effects and post-retrieval processing which does not involve discriminating aspects of previous episodes in which old test items were presented. Once more, a number of PET studies have already shown that regions of left prefrontal cortex are preferentially engaged during tasks involving the generation of semantic information (e.g. see Buckner and Tulving, 1995). Such findings helped to guide the formation of

Buckner and Tulving's HERA model, mentioned above. This model suggests that left prefrontal cortex may play a role in semantic retrieval. ERP studies could be carried out to determine whether sustained frontally distributed ERP effects were associated with performance on a task involving semantic, rather than episodic, retrieval. For example, subjects could be presented with a list of old and new words, with instructions to generate a semantic associate only for items judged to be old. This task does not require further discrimination of attributes of study episodes, yet it does require subjects to judge the old/new status of items, and then on this basis perform further processing based on an attribute of the old item (i.e. its meaning). The analysis of ERP old/new effects in this study may reveal whether or not a frontal old/new effect, perhaps larger over the *left* than the *right* hemisphere, is elicited specifically by the requirement to retrieve from semantic memory.

A further possibility would be to investigate whether frontal old/new effects occur on tasks which do not involve an episodic memory component at all. The 'category exemplar production' task (e.g. Blaxton, 1989) could be employed to study this issue. This task requires subjects to generate a particular instance of a category (e.g. ZEBRA) in response to a category name (e.g. ANIMAL). Typically, such tasks are employed to study conceptual priming (e.g. Roediger and McDermott, 1993). In the present case though, this task could be used to study the manipulation of information retrieved from semantic memory. Without any study phase as such, subjects could be presented with the cue 'ANIMAL', and be asked to retrieve the name of an instance of the category. The task involves retrieving from semantic memory an instance of this category, but this retrieval does not depend upon access to a specific episode in which a Zebra was encountered. The task thus makes no demands upon episodic memory, but instead measures processing which mediates the use of cues for semantic retrieval. ERPs in this condition could be compared with a baseline condition requiring, for example, the category cue only to be read.

A particularly interesting prediction which could be made here is that a left parietal ERP effect should not be observed, since there is presumably no need to engage the core medial temporal lobe memory system to retrieve a specific prior encounter with

a zebra. On the other hand, a more frontally distributed effect may, or may not, be observed if the task engages more general processes which mediate the on-line explicit retrieval and manipulation of semantic information guided by the category cue. The above study could also include a condition where category name cues are repeated some time after their initial presentation. On second presentation, the subject then has to remember, and give, the category instance used when the category name was first presented. The contrast between ERPs for this condition and for the condition where the category instance was first retrieved may reveal brain activity specific to the use of the category cue to guide episodic retrieval. This would allow a further contrast to be made between ERP effects for initial semantic retrieval (i.e. ERPs for the reading baseline vs semantic retrieval conditions) and ERP effects for episodic retrieval based on the category cue (i.e. ERPs for the semantic retrieval vs. episodic retrieval conditions).

11.9 In Conclusion

The six studies presented here provide the first detailed reports of ERP effects associated with explicit and implicit retrieval on tests of cued recall and stem completion. The relationship between these ERP effects and those previously observed on other direct tests of memory was also investigated by directly contrasting ERP correlates of explicit retrieval on the cued recall and recognition memory tasks. Two component features of the cued recall and recognition memory ERP effects were found to be highly similar: ERP effects for each task were comprised of parietally and frontally distributed components which differed, as a function of task, only in two basic respects. First, the parietal and the frontal effects for cued recall appeared to be somewhat delayed in onset latency relative to that for recognition memory. Second, the hemispheric asymmetry of the frontal effect for cued recall was typically less marked than that for recognition memory.

The two ERP components were interpreted in terms of processes contributing to the recollection of previous episodes in which words were presented for study. A basic

distinction between retrieval and post-retrieval processes was invoked to account for differences in the two components. The parietal component was related to retrieval processing sufficient to judge test stimuli as having been presented at study. The frontal component was related to post-retrieval processing of information which may be more under strategic control, and therefore more sensitive to factors extrinsic to those affecting retrieval success per se.

Similar ERP findings have now been observed across a variety of direct and indirect tasks (recency memory, associative recognition, cued recall, recognition memory, source memory, stem completion, perceptual identification, lexical decision), which indicates that ERPs provide a rather general marker of explicit retrieval. One important task for future research will be to generate paradigms which relate quantitative and qualitative modulations of these ERP effects to manipulations of retrieval and post-retrieval processing. Such studies promise to further illuminate the functional neuroanatomy of explicit retrieval, which the present studies only begin to explore.

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Appendix

A. Stimuli employed in experiments 1 and 2

SCHOLAR	SYMPHONY	BEARD
SENATE	CLOUD	DIVE
ABSENCE	BEER	PLUG
STAR	SWEAT	PORCH
LENS	HIGHWAY	REBEL
REMOVAL	MERCHANT	NOTION
ARRIVAL	CARD	BASEMENT
NATIVE	PATENT	TRAVEL
ARTERY	FALLOUT	ETHIC
ENTRANCE	GARAGE	SHELL
APPROVAL	TUNE	VISITOR
WILL	MILK	DAMAGE
DUST	THOUSAND	COAT
PURCHASE	MORTGAGE	THEME
REALM	FLASH	SUICIDE
UNCLE	CELLAR	GLIMPSE
PICNIC	IDENTITY	SHIFT
CLERK	ENGINE	ASPECT
VINE	SUNLIGHT	QUANTITY
VACATION	NAVY	MONK
VICTORY	COLD	COUSIN
SWITCH	DEVIL	LEAD
AVENUE	BENCH	ORIGIN
ACADEMY	ATOM	DISASTER
MUSEUM	COOK	PERCENT
PACE	WISDOM	FRUIT
LIBERAL	SUPPER	SERUM
FORT	SCENERY	SELF
CRAFT	TURN	FIRM
INCIDENT	DEPTH	SCREEN
CAVE	WELFARE	WEATHER
SLOPE	BULLET	CLARITY
MOON	BAND	COMPOSER
THIEF	BIRTH	CHEST
VERSION	SLIP	LOCK
GLANCE	VALLEY	TENDENCY
BRIDE	PRAYER	REPUBLIC
STUDIO	EQUATION	ESCAPE
CRITIC	BUSH	DINNER
WHISKY	EXCHANGE	TEAR
MELODY	SPAN	SOUL
HALF	CURVE	BOOT
DENSITY	TRUST	DECADE
HARMONY	FERRY	ACCIDENT

TARGET
BRUSH
STORM
SNOW
MARINE
BARREL
BATH
MOLD
RIDER
FIGHT
PROTEIN
GROVE
FLUX
ACTOR
VESSEL
MATURITY
FAME
LINGUIST
HEIGHT
COSTUME
HUMOR
DANCER
BIOLOGY
PALACE
CLIENT
LAUGHTER
CITIZEN
LACK
MAIL
EARNING
SILENCE
FLIGHT
MEMORY
ESTATE
FOLK
CAPE
PINE
QUEEN
OBSERVER
PENCIL
STICK
OPTIMISM
FABRIC
ADVICE
CANCER
MAGAZINE
VITALITY
BORDER
TEXTILE
ADULT
MASTER
TEMPLE

LUMBER
MESSAGE
FACTORY
TOPIC
AWARD
HANDLE
HOLIDAY
VIRTUE
SIGNAL
PITCHER
TANK
ABUSE
STEAM
SUMMARY
SQUAD
GUILT
BALLET
HEAVEN
AMATEUR
WHEEL
POLE
WASTE
PHONE
PLANET
CIRCUIT
DRIVE
REVENUE
TIMBER
ORGAN
MEDICINE
LUNCH
TIDE
DRAMA
BONE
LEGEND
CATEGORY
RACE
MISTAKE
JUNIOR
CROWD
POST
WRIST
MAJORITY
SAND
PAGE
CALENDAR
WITNESS
DRESS
BELT
PILOT
ANODE
FATE

SCORE
HERO
EXAMINER
REGARD
OCCASION
MEAT
FOUNTAIN
EVIL
FRACTION
HUNDRED
STRUGGLE
FELLOW
CREDIT
WANT
GLORY
FANTASY
RANK
THROAT
LOAD
AUTHOR
TOUCH
TERROR
PEAK
DESK
FLESH
DOME
FAILURE
WARFARE
FURY
BOUNDARY
CAUSE
FARMER
COPY
ILLUSION
BLANKET
AMBITION
FIST
PETITION
INQUIRY
ARCH
GRASS
FASHION
BEDROOM
SKIN
OUTPUT
HURRY
WATCH
CRUELTY
PAIR
DEALER
DOCUMENT
EMBASSY

ROUTE
CHAIN
SLEEP
SCALE
CULTURE
ACRE
EXERCISE
CUSTOMER
OPPONENT
SPORT
TREND
SHORE
OPERA
SOLID
SECRET
GRIP
PHASE
SALARY
CAMPUS
PHRASE
SPECTRUM
TRIBUTE
AIRPORT
TONGUE
TAPE
CONTEST
INDEX
HONEY
PRISON
SMOKE
REQUEST
CEREMONY
DARK
TACTIC
LAMP
PRESENT
TALENT
BUREAU
EDITION

HINT
PARTNER
RATIO
WING
MODE
SNAKE
RESERVE
BUNK
PASSION
MINIMUM
DOUBT
POPE
BLUE
HABIT
COCKTAIL
TEENAGER
FRONTIER
FLOW
HELL
UNIFORM
TROOP
REFORM
METAL
CHORE
FRICTION
FUNERAL
BREATH
DELAY
SPREAD
SURVIVAL
COVER
SLUM
PLENTY
RAILROAD
MOTIVE
EMPHASIS
TWIST
VIOLENCE
TOMB

HOST
DROP
VENTURE
SHADOW
CABIN
LIVING
SEARCH
RUSH
INFANTRY
ARGUMENT
POND
PANEL
GREASE
CORN
CLUSTER
SPITE
BOTTLE
MANKIND
ENERGY
MOUSE
TIRE
WALK
PLOT
SETTING
MYSTERY
BUDGET
INITIATE
KINGDOM
INVASION
HORIZON
SPUR
DIAMETER
MALE
CASH
VELOCITY
ANALOGY
WHOLE
NONSENSE
WORSHIP

B. Stimuli employed in experiments 3-6

REQUIRE	FLOOD	COPIOUS
AIRCRAFT	SLEET	TEAK
ATOM	KING	PETULANT
SETTING	MERGE	FAMILY
TUNIC	PANDER	TENDON
DUSKY	SUITCASE	EMBARASS
PONY	CAUTERIZE	REFLEX
MONOLITH	SCENARIO	AWASH
GROUND	SLOTH	ARRIVAL
CELLULAR	HARVEST	ESTUARY
TERRACE	BALLET	DEPLOY
OBSCENE	ARGUMENT	BONE
VIOLATION	ACADEMIC	DANK
HALF	ENERGETIC	CREMATE
MODEL	MAJORITY	LAMB
OPTIC	TAPDANCE	PLEASURE
MEANDER	TOURIST	VICE
RUSTIC	MASH	REGARD
CAVORT	NATIVE	IMPULSE
EXCEPT	TARGET	SERUM
QUELL	WELFARE	MOTIVATE
PAIN	HANDGUN	ACTUAL
TOME	CLIFF	WRING
GRIMACE	MYSTERY	GUILD
SNOB	FISHING	FLINCH
DRAFT	WITNESS	HEIRESS
SPUN	DENSITY	GRAZE
REBEL	TOPPLE	CHOKE
EDITION	MELD	DEVIL
SLUDGE	MOLLIFY	TOWNSHIP
DEARTH	WORRY	INCUBATE
SYMPHONY	CLOTHES	GLOWER
RACIAL	BELT	HOSTESS
CALENDAR	PACING	REALITY
BANNER	BLUNT	PENDANT
SENSUOUS	OCCUR	PROFIT
CASKET	HUNTER	SCAVENGE
SURGERY	DECADENT	ARTISAN
FIGMENT	PINHOLE	BOOM
FERMENT	SHOE	SOLUTION
FURY	CLUB	DREAM
TEMPLE	ADULATION	WATERSHED
VENISON	INIMICAL	MARBLE
STREAM	SUNSET	FLEE
SEAR	BEND	LOATHE
INVISIBLE	BASS	TRITE
MALIGN	SCRAWL	BORROW
SCHOOL	PORTRAY	FALLOUT
FRUITION	OPPONENT	SMOTHER

STORM
BARREN
SLICK
FROG
TUBING
LUNAR
SECEDE
CANDOR
TITTER
WALLOW
THRUSH
BLOODY
MIST
RAINCOAT
POSTCARD
QUANTITY
HIGHNESS
TONGUE
VISIBLE
FAIRY
SPREAD
DIGNIFY
LIBERTY
DEBT
PALATE
MUSIC
STUDY
VEST
DOUGH
CROUCH
GLIMMER
PLOWMAN
FINITE
FATTEN
VALVE
BOTTOM
HINDSIGHT
CURRY
ACRE
BRUNCH
FOUND
CLARITY
TURN
ACCLAIM
SPITTAL
MATERNAL
BULLET
ARCADE
BATTLE
TRUCE
SPARE
CART

COVERT
HURTLE
FLUCTUATE
EVIDENT
MAIL
THEFT
WISTFUL
STEEL
METTLE
DOMINANT
GLAD
DAMN
CITATION
PRAM
SHINE
DIALECT
THONG
SPEECH
CUSHION
IDEAL
EXERT
RATING
MINOR
CAMPFIRE
BREATH
ANCIENT
GREET
REST
WANGLE
CRUST
POLITICS
SUPINE
PHYSIQUE
FABRICATE
HABITANT
FARM
CRIME
PRISON
ROUTINE
DISMAY
SCOFF
PITFALL
DIVE
BUNGLE
TALISMAN
SWELL
SIGHT
PRECIOUS
TACTILE
HORROR
LAUDABLE
MOROSE

CIRCUIT
PHOBIA
LUMINOUS
RIDER
FELINE
PLUNGE
ENGINE
THIMBLE
RANCID
ANOMALOUS
SUMMIT
TEETER
FLASH
CATALOGUE
CABINET
ABUSIVE
PHRASING
NONSTOP
PHASE
MEDLEY
MOONLIGHT
AUTOGRAPH
TREASURE
CHARM
TRAITOR
ORIENTAL
COMIC
SAND
REVILE
ABSTAIN
FANCY
COLLEGE
SHELTER
STATUS
LIVING
OUTSIDER
CLENCH
UNCORK
EQUATION
COURTIER
PLAY
DRIP
VACANCY
WINCH
SPOT
ESCAPEE
CORONARY
BLANK
OPERATOR
TIME
POPULOUS
TWINE

JUNKIE
HERETIC
LENTIL
FRAGRANT
CRAB
BEACON
FACTION
MESS
BRAVE
PARTISAN
ILLOGICAL
LEADER
BOULDER
LOCUST
INFLAME
RELENT
OFFEND
ASPECT
PURE
BEHAVIOUR
FIREMAN
SOUR
COSTUME
EMULATE
EMPLOY
ANARCHY
TEXTBOOK
INDOOR
HOLY
SAME
FASHION
CAPE
VIRILE
COCAINE
VINEGAR
FRIVOLITY
SWISH
SALOON
VERIFY

PATRIARCH
BEDLAM
HONE
WILLING
RADIATOR
DINOSAUR
FOLK
CERTAIN
SHATTER
CONFIDE
WHISPER
BURY
DESOLATE
COACH
PEARL
SACRAMENT
ETHNIC
LINE
BEEHIVE
PERSON
CULPRIT
ENTRANCE
SKID
LEGISLATE
GARRISON
WHORE
LACE
REPUDIATE
VITALITY
EARLY
MOUTH
REMAND
HUMID
HELMET
STICKY
DROWSE
AMBIANCE
HEARSAY
FUNGUS

PASSAGE
SNARL
SCISSORS
ADVICE
ORGY
BUSHEL
WEALTH
APPETITE
TANKER
FORT
MANKIND
EXAMPLE
DOCTRINE
TROT
DARK
MILITARY
WHEEZE
FRENZY
MAGIC
SQUEAK
SILICON
CHILDHOOD
SELDOM
PILLAGE
BIRTH
PAGAN
NAVY
PICTURE
WARN
NOTABLE
UNIFORM
DELICATE
MEMO
CHEAP
BRICK
TIDINGS
WASTE
COOLANT
TIRESOME